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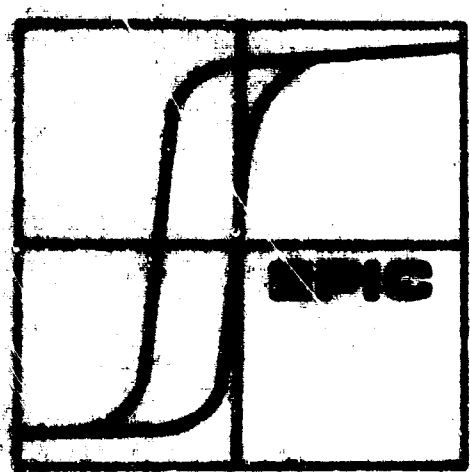
SULFUR HEXAFLUORIDE

Data Sheets

John T. Milek

DS-140✓

October 1964



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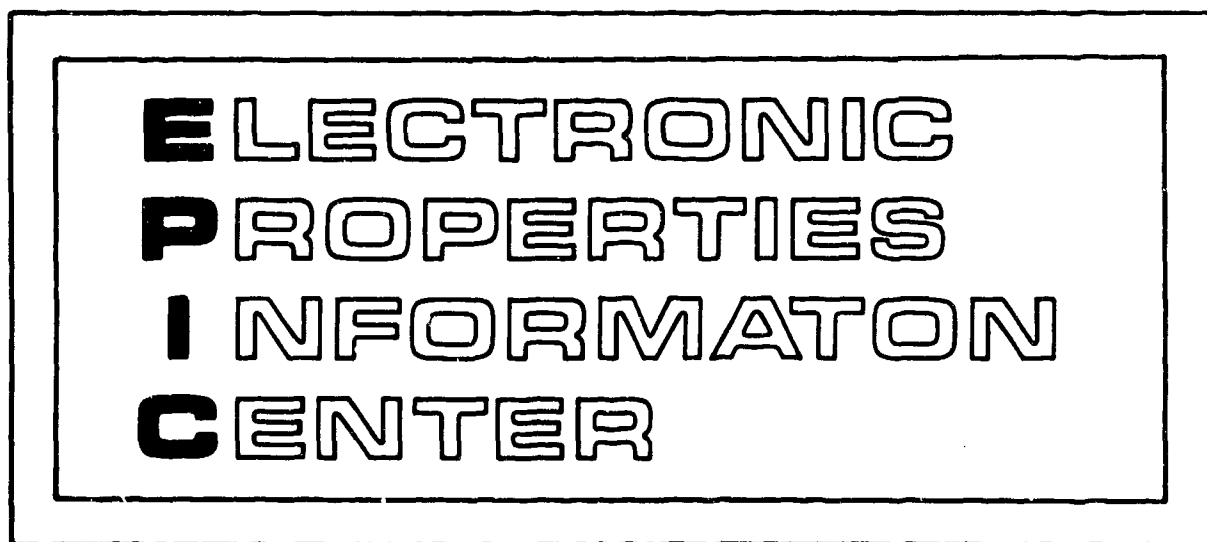
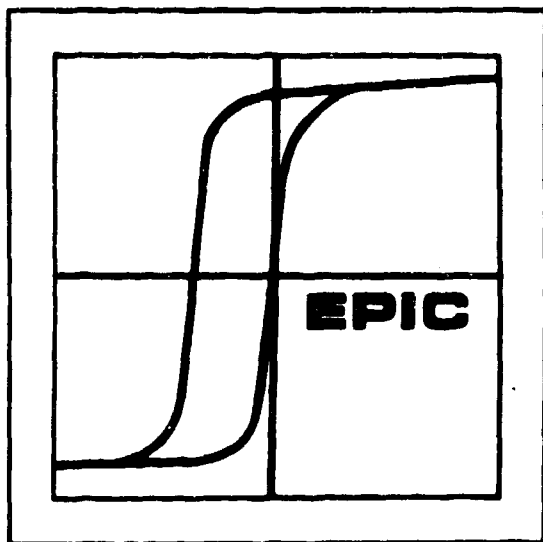
SULFUR HEXAFLUORIDE

Data Sheets

John T. Milek

DS-140

October 1964



FOREWORD

This report was prepared by Hughes Aircraft Company under Contract No. AF 33 (615)-1235. The contract was initiated under Project No. 7381, Task No. 738103. The work was administered under the direction of the Directorate of Materials and Processes, Aeronautical Systems Division, with Mr. R.F. Klinger acting as Project Engineer.

The Electronic Properties Information Center has been established to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. A modified coordinate index to the literature is machine-stored and printed for manual use. The Center publishes summary reports, thesauri, glossaries, data sheets and similar publications as sufficient information is evaluated and compiled. This report consists of the compiled data sheets on Sulfur Hexafluoride.

Many persons have contributed to the program which this report represents. The author wishes especially to acknowledge the contributions of the following: J.W. Atwood, C.L. Blocher, D.L. Grigsby, D.H. Johnson, H.T. Johnson, T.J. Lyndon, M.S. Neuberger, E. Schafer and C.A. Schill.

ABSTRACT

A compilation of the electrical properties of Sulfur Hexafluoride, a dielectric gas is presented. Electrical properties include corona, dielectric constant, dissipation factor and dielectric strength. The latter property data section is segregated into parameter effects as follows: pressure, gap distance, temperature, electrode configurations and gas mixtures. Each property is compiled over the widest possible range of parameters obtained in a thorough search of the world's literature.

This report has been reviewed and is approved for publication.



H. Thayne Johnson, Head
Electronic Properties Information Center


John W. Atwood
Project Manager

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INTRODUCTION

In June 1961, a program was initiated under the direction of the Air Force to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. Placed at Hughes Aircraft Company in Culver City, California, the program, now called the Electronic Properties Information Center, was originally intended to cover ten major categories of materials: Semiconductors, Insulators, Ceramics, Ferroelectrics, Metals, Ferrites, Ferromagnetics, Electroluminescent Materials, Thermionic Emitters and Superconductors.

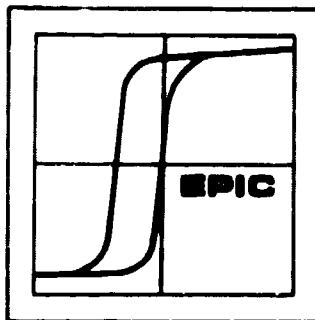
During the first year, studies were completed on the Semiconductor and Insulator categories; and Ceramics was discontinued as a separate category and subsumed under the other nine. Vocabulary studies have now been completed on all categories, and retrospective documentation is virtually complete for Semiconductors and Insulators. A full index to the literature is maintained; and publications such as data sheets, summary reviews, glossaries and thesauri are issued periodically. The use of the Center and these publications are available to anyone wishing information within the scope of the Center's objectives. A full list of publications to date appears at the end of this report.

This report contains data sheets on Sulfur Hexafluoride. The data sheets have been compiled directly from the literature. Articles are allowed to accumulate until it is judged that a sufficient number are available on one material for adequate evaluation. The manual modified coordinate index is then used to retrieve all literature on the material to be compiled. Bibliographies are checked to make sure that valuable and relevant literature is not overlooked. Then the assembled literature is given to the specialist doing the evaluation and compilation.

Evaluation is confined to primary source data except when only secondary citations are available. If equally valid data are available from several sources, all are given. Data are rejected when judged questionable because of faulty or dubious measurements, unknown sample composition, or if more reliable data are available from another source. Selection of data is based upon that which is judged most representative, precise, reliable and covers the widest range of variables. The addition of new data to a previously evaluated property requires a reappraisal of the reported values. Older data may be deleted if the new data are judged more accurate or representative.

After a thorough analysis and evaluation, the data are compiled into data sheets which present it in its most optimum form. This will be, primarily, but not limited to, curves or tabular form. Where possible, graphs are adapted directly from the original sources. If this is not possible, they are drawn from data compiled from the articles. Where thought important, notes are entered with each graph to help the user.

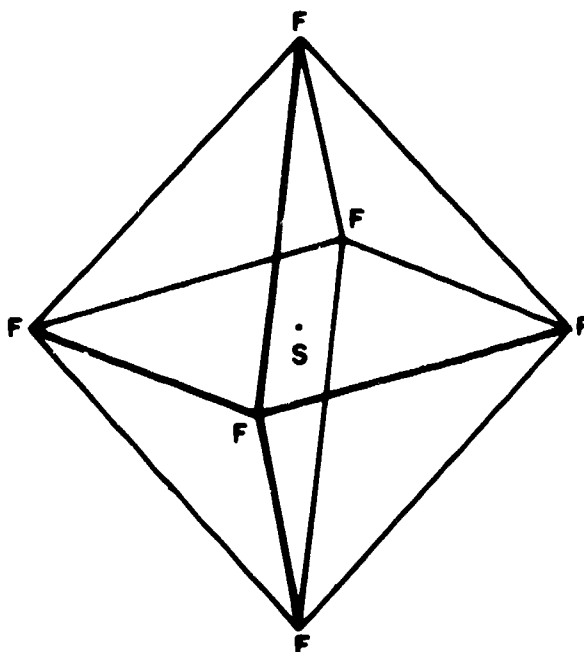
The references, from which the data are drawn, are shown by reference number below each graph with the full bibliographic information at the end of the data sheets. The bibliography is referred to and listed in the order of entry into the Center (accession number). This provides a quick cross reference into the index used with the literature.



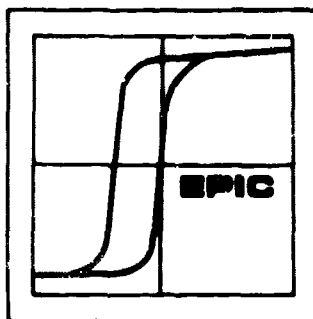
SULFUR HEXAFLUORIDE

General Description

Sulfur Hexafluoride (SF_6) is a stable, non-toxic gaseous dielectric with excellent electronegative behaviour or characteristics. Its structure is such that all six fluorine atoms are at the corners of a regular octahedron with the sulfur atom at the center:

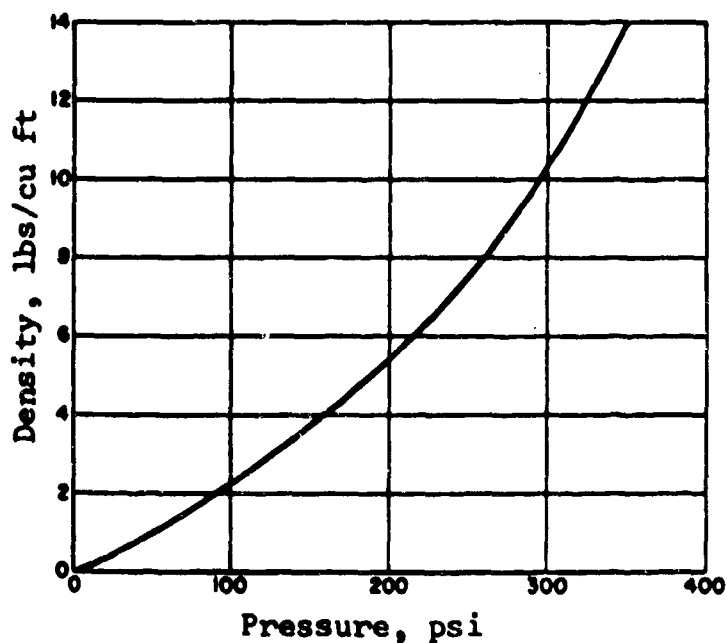
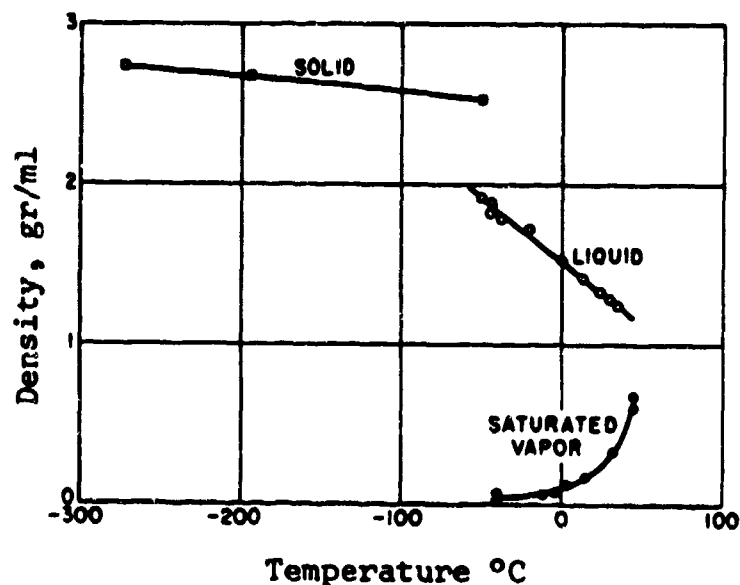


In pure form SF_6 gas does not have any odor and is harmless; it does not burn and is heat resistant up to 500°C depending on conditions. At 150°C , SF_6 begins to undergo chemical decomposition and is initiated catalytically to various degrees by different metals. Possible decomposition products are SF_2 , SF_4 , S_2F_{10} and HF . It is insoluble in water and has a molecular weight of 146.06. In the gaseous state, SF_6 follows the ideal gas laws fairly closely.



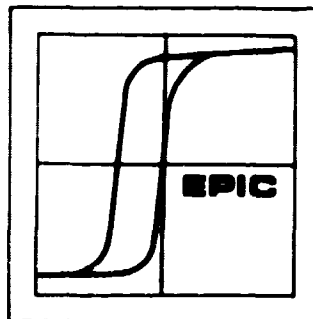
Physical Properties

Melting point	-50.8°C at 32.5 psia (-58°F to -68°F)
Sublimation temperature	-63.8°C (-80°F)
Critical temperature	45.547 0.003°C (113°F to 129°F)
Critical pressure	545.47 psia
Critical density	0.730 gm/cc



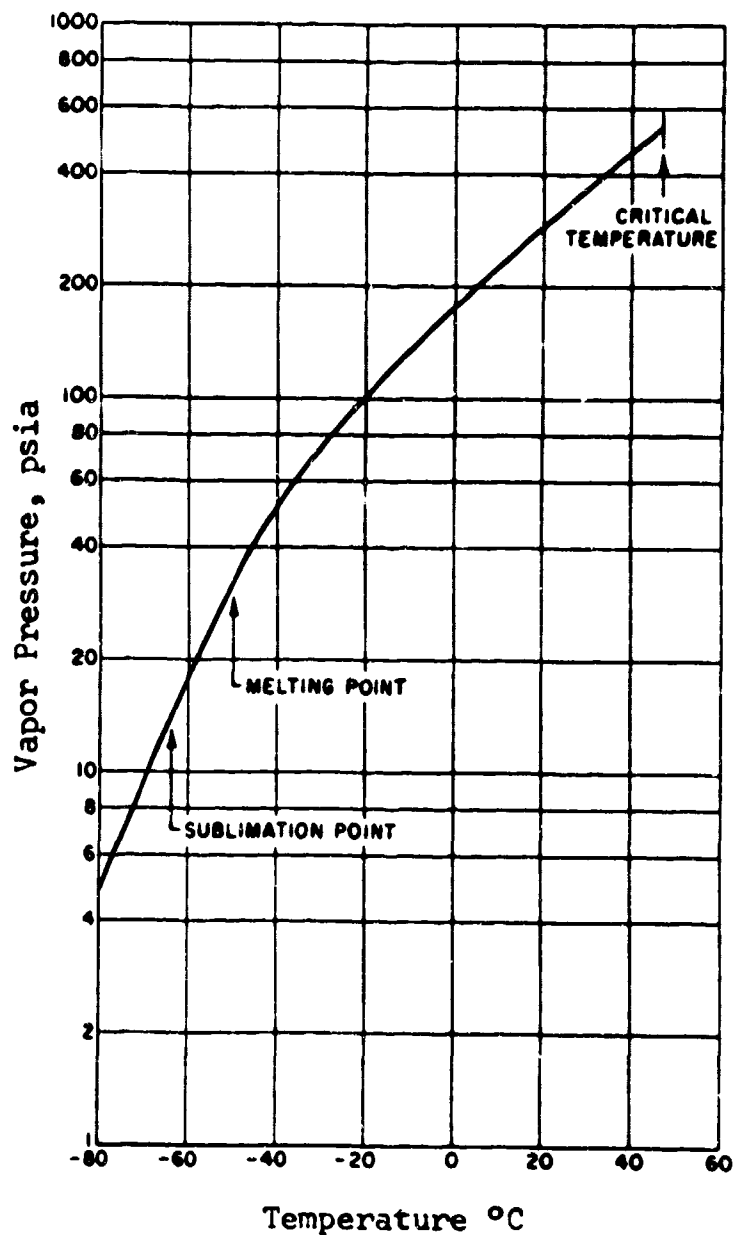
The pressure density relation
for sulfur hexafluoride.

The density of sulfur hexafluoride over
the temperature range from -273 to 45°C.

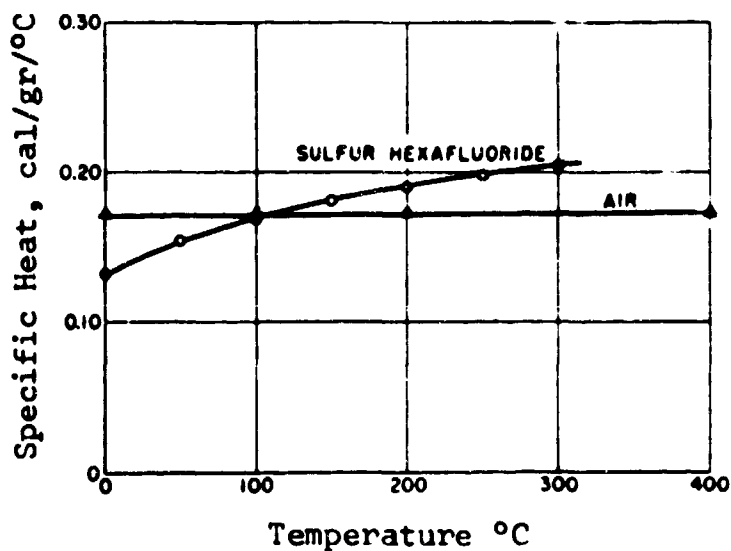


Physical Properties

The vapor pressure-temperature relation for sulfur hexafluoride.

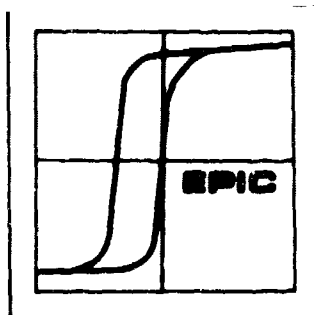


[Ref. 16775]



The specific heat of sulfur hexafluoride measured at constant volume.

[Ref. 16775]

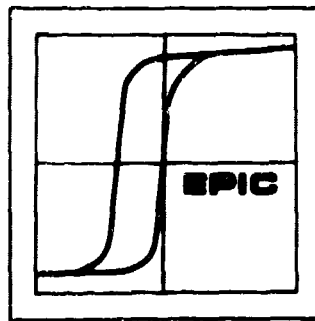


Applications

SF₆ provides an outstanding insulating medium for a wide range of electrical and electronic equipment and applications. It is remarkably inert and possesses exceptional thermal stability, unique arc-quenching properties and high dielectric strength. The gas has found dielectric applications in the following: waveguides, x-ray apparatus, switch gear, cathode ray accelerators, television filter plexers, audio equipment, airborne electronics, Van de Graaf machines, transformers, radar duplexers and gap tubes. Sulfur Hexafluoride is being used extensively as a means of obtaining high peak power performance in waveguide systems.

In a recent review study at Rome Air Development Center of the available microwave behavior of SF₆ it was reported that power ratios (breakdown power of SF₆ over that of air at normal pressures with all other parameters constant) of SF₆ varied from a low of 3 to a high of 40 in the literature. The mechanisms of these inconsistencies were discussed in terms of geometric configuration, contamination, localized hot spots, localized corona discharges, etc. (Ref. V.C. Vannicola, "Sulfur Hexafluoride in High-Power Microwave Systems", Rome Air Development Center, Report no. RADC-TDR-62-443, November 1962. AD 289-954.)

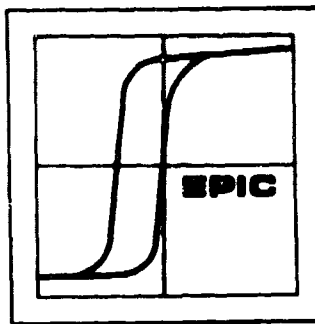
Leeds and Friedrich (Engineers Digest, V. 13, p. 1073-1075, 1962) reviewed recent developments in the use of SF₆ for circuit breakers. SF₆ had superior arc extinguishing properties because it acted like an "electron sponge." This has made possible its usage in a variety of different commercial switchgear apparatus: plain breaks, self generated gas flow by arc heating, gas flow by puffer action and gas flow by opening blast valves between high and low pressure reservoirs.



Notes

Sulfur Hexafluoride is currently undergoing study and testing by the Electrical Tests Subcommittee II of ASTM Committee D-27 on Electrical Insulating Liquids and Gases. The Gaseous Dielectrics Section of the Subcommittee has undertaken the development of a standard test cell for the evaluation of the dielectric strength of SF_6 and other gases. Round-robin tests have been conducted and some results reported in the "Symposium on Electrical Insulating Gases," ASTM-STP No. 346, 1963, Philadelphia, Pa., American Society for Testing and Materials.

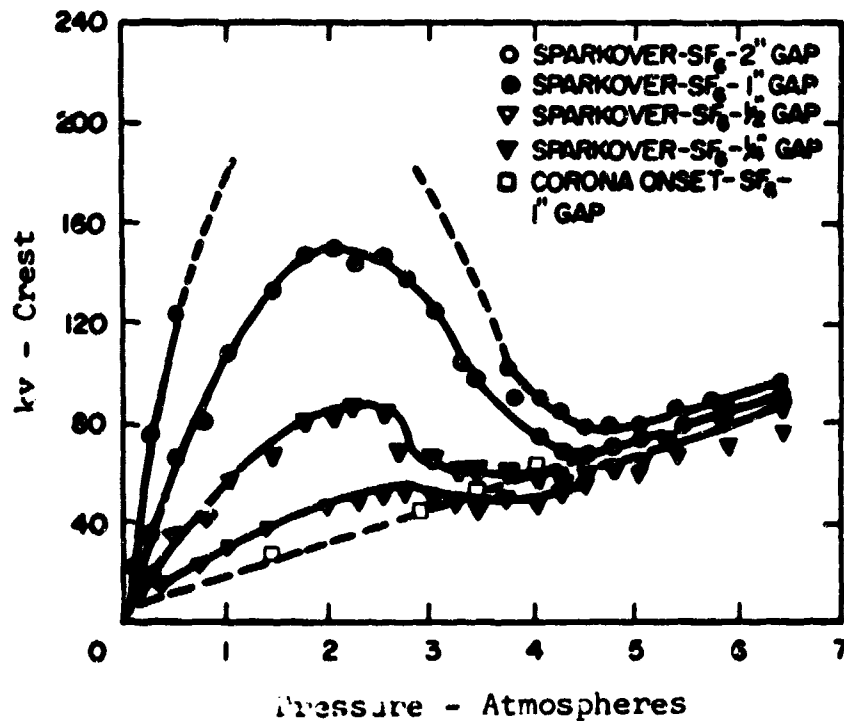
The EPIC method of dielectric strength data presentation has fallen in line with the philosophy of ASTM Committee D-27 on Electrical Insulating Liquids and Gases as expressed in M.L. Manning's article "Gaseous Insulation: Its Importance and Need for Test Methods," ASTM-STP No. 346, 1962. p. 3-23. The philosophy involves the segregation of dielectric strength data by a) electrode geometry effects, b) by pressure effects, c) gap distance effects, d) type of applied voltage.



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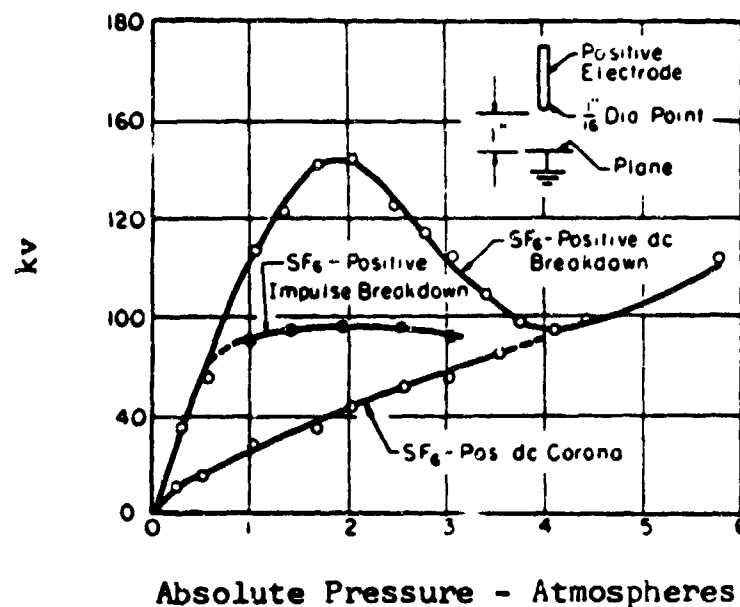
SULFUR HEXAFLUORIDE

CORONA EFFECTS



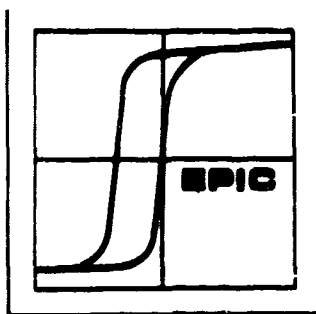
A-C spark-over and corona onset voltages of sulfur hexafluoride for indicated gaps between 1/16 inch hemisphere point and 6 inch diameter plane in 12 inch diameter steel tank as a function of pressure.

[Ref. 11302]



Sparkover and corona onset voltages of SF_6 in a 12 in. diameter steel tank as a function of pressure at 25°C.

[Ref. 10936]



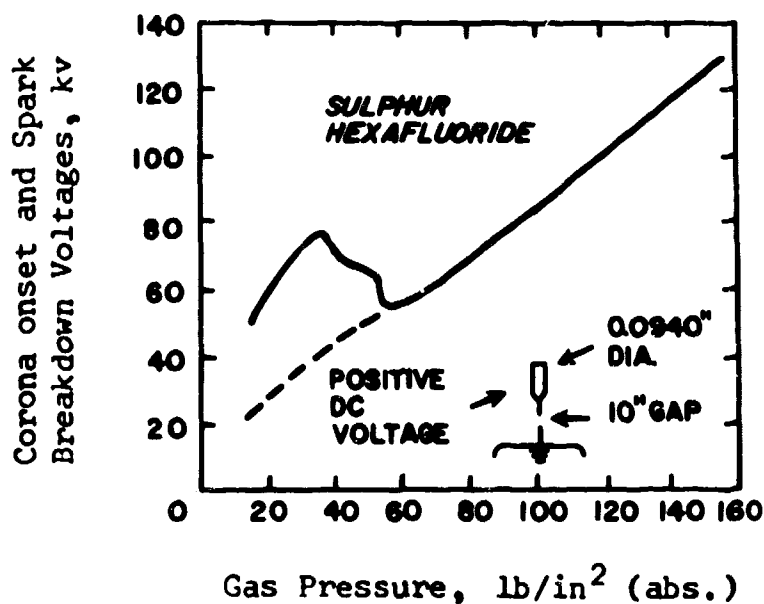
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SULFUR HEXAFLUORIDE

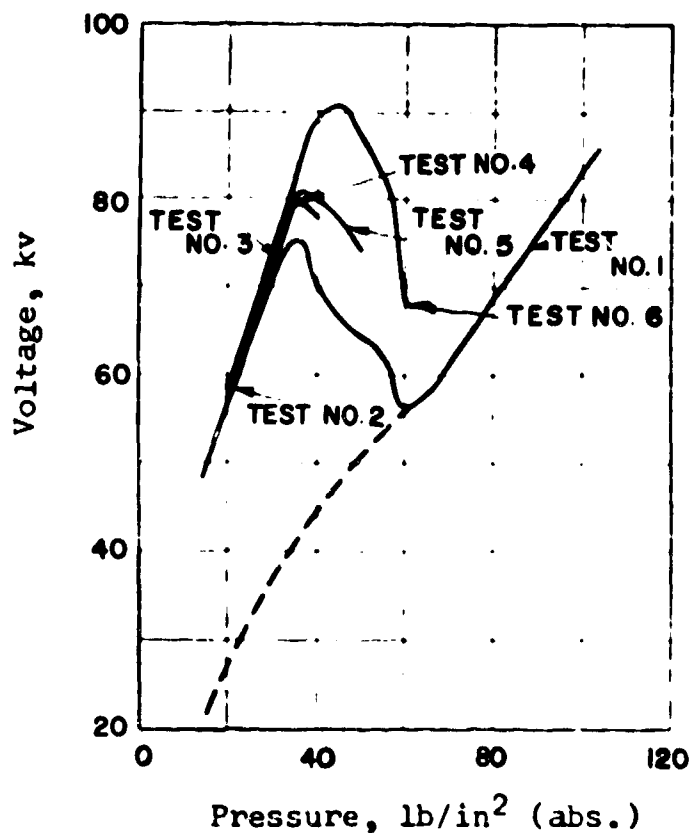
CORONA EFFECTS

Corona onset voltage of sulfur hexafluoride as a function of gas pressure.

- Spark breakdown voltage
- Corona onset voltage



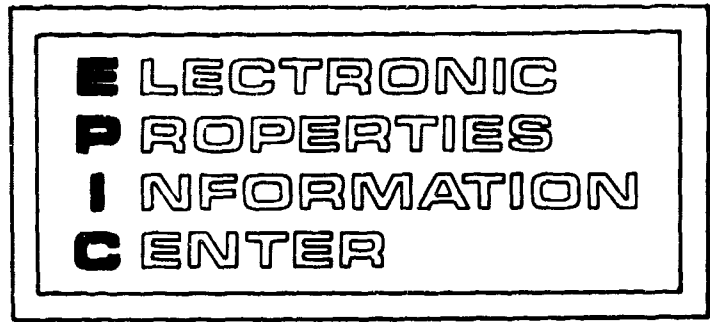
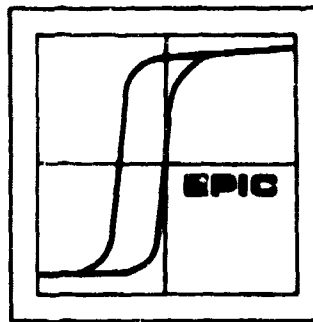
[Ref. 1655]



Corona onset and spark breakdown characteristics for sulfur hexafluoride.

- Corona onset voltage
- Spark breakdown voltage

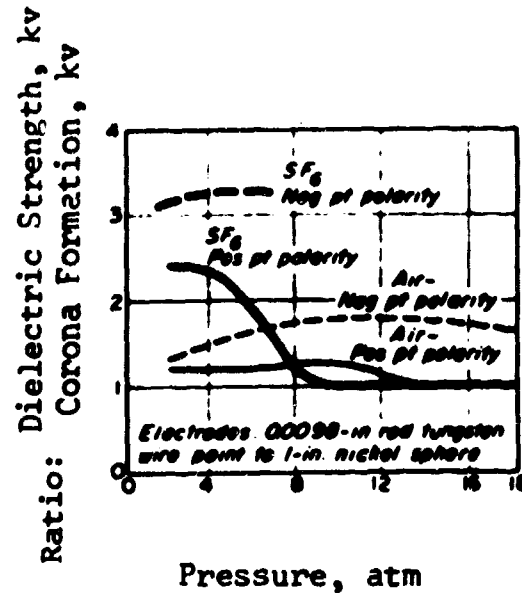
[Ref. 1853]



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SULFUR HEXAFLUORIDE

CORONA EFFECTS



Breakdown voltage to corona voltage ratio as a function of pressure for sulfur hexafluoride and air under both positive and negative point polarity.

[Ref. 6140]

Corona Onset and Flashover Voltage in SF₆ Gas, 3/4-Inch Diameter Square-Cut Rod-to-Plane Electrodes

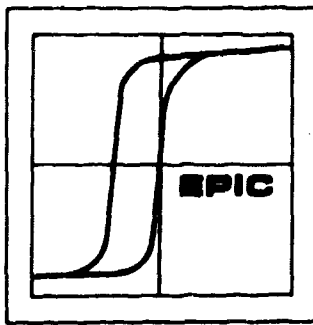
Full-Wave Tests (1 1/2 x 40 μsec)

Pressure, Psig*	Spacing, Inches	Corona Onset Voltage, %		Flashover Voltage, %	
		Point Negative	Point Positive	Point Negative	Point Positive
0	1	92	100	200	110
15	1	125	128	254	145
0	6	85	100	324	162
15	6	132	140	354	147

Note: For each spacing, the corona onset voltage at atmospheric pressure and positive point = 100%.

* Pounds per square inch gage.

[Ref. 6209]

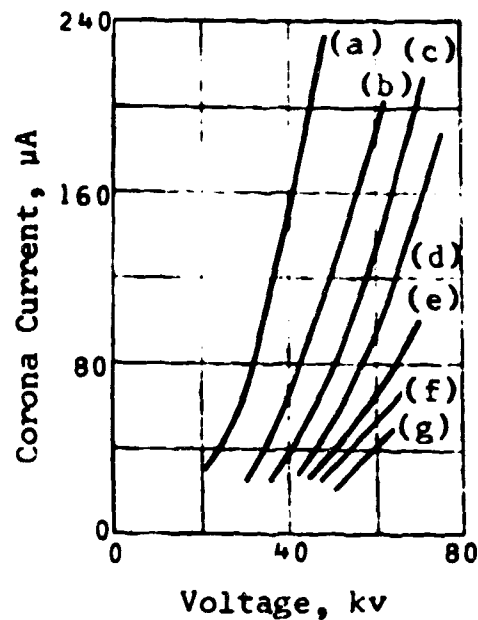


SULFUR HEXAFLUORIDE

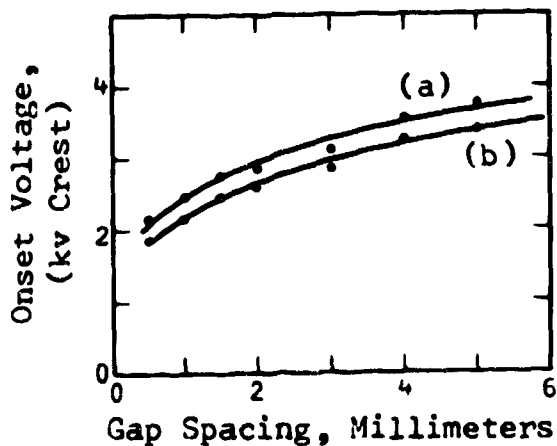
CORONA EFFECTS

Corona current/voltage characteristics
for sulfur hexafluoride.

- (a) 15 lb/in² absolute
- (b) 25 lb/in² absolute
- (c) 30 lb/in² absolute
- (d) 35 lb/in² absolute
- (e) 40 lb/in² absolute
- (f) 45 lb/in² absolute
- (g) 50 lb/in² absolute



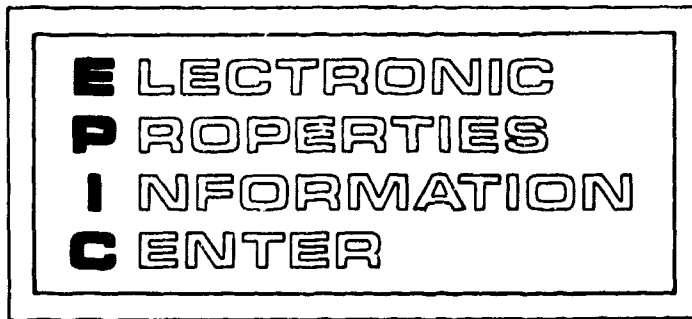
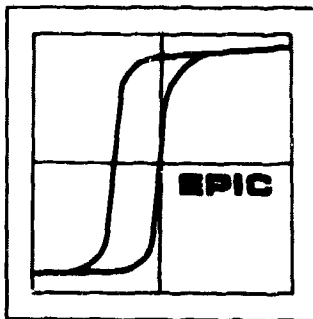
[Ref. 1853]



Corona onset voltage as a function of
gap spacing in point-plane corona test
(corrected to 760 mm) using polonium α -
source. Radius is 0.060 mm.

- (a) SF₆, point positive
- (b) SF₆, point negative

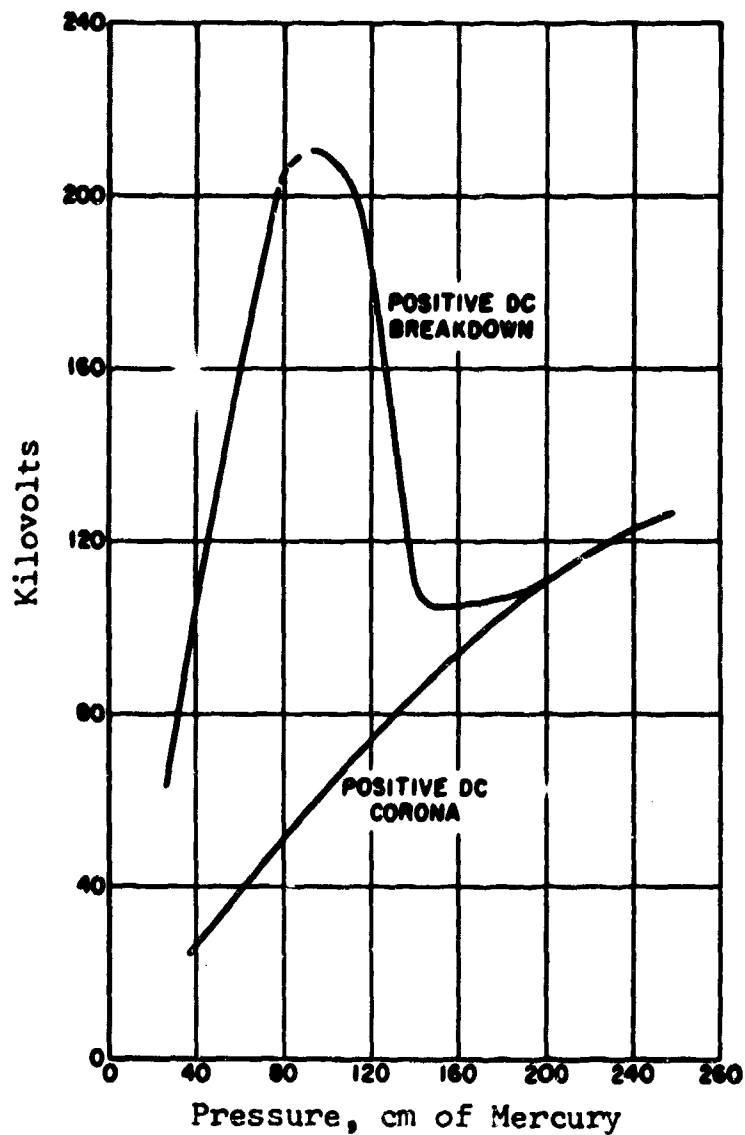
[Ref. 6209]



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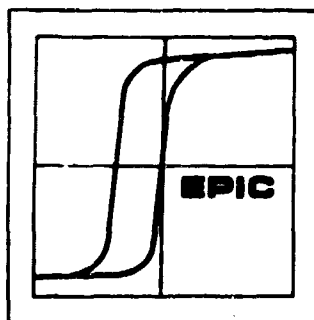
SULFUR HEXAFLUORIDE

CORONA EFFECTS



The corona breakdown relation for sulfur hexafluoride as affected by pressure.

Electrodes - 1/2" square rods
Test Gap - 2 inches



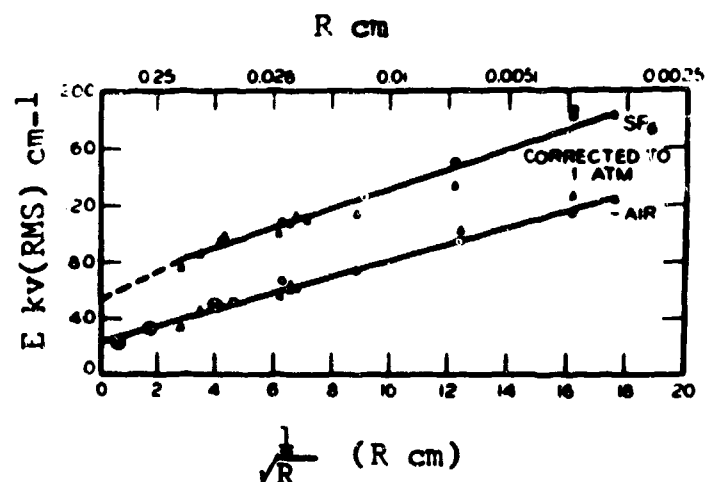
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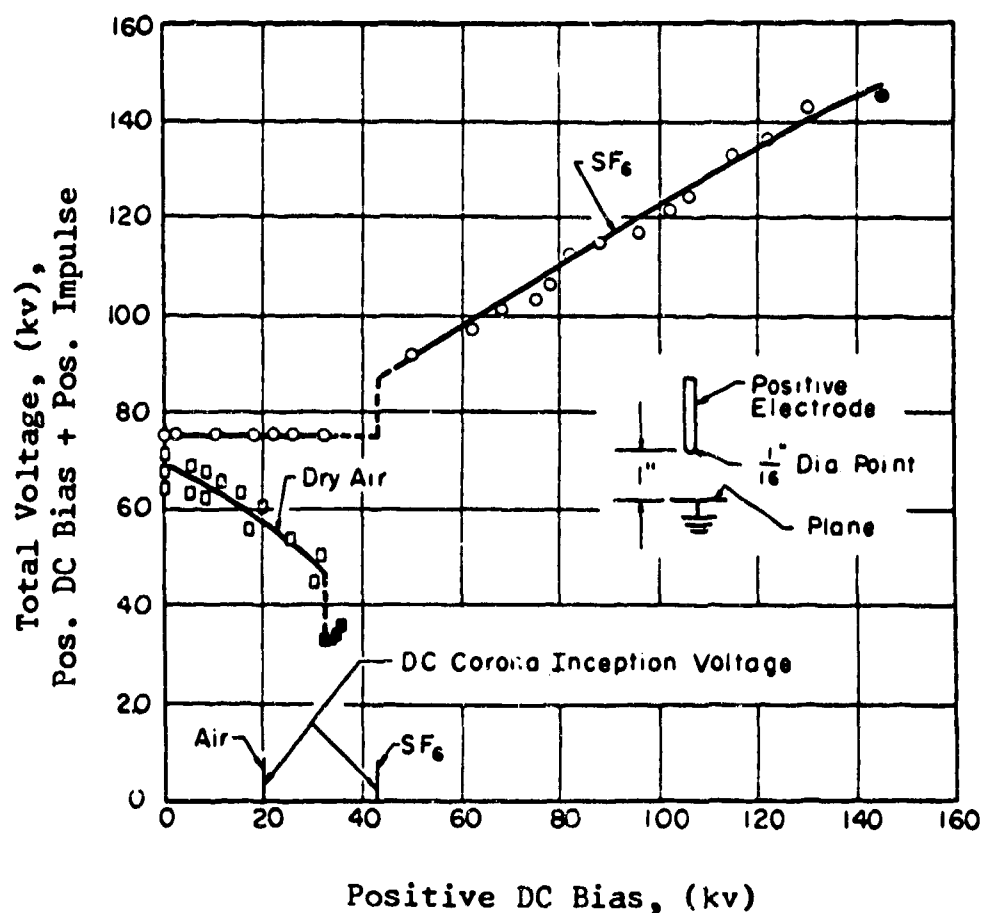
CORONA EFFECTS

Corona extinction field (-) E as a function of $1/\sqrt{R}$ where R is radius of wire in 1/4 inch or 1/2 inch coaxial cylinder.

- Peek's data
- 1/2 inch outer cylinder
- 1 inch outer cylinder
- △ 1/4 inch outer cylinder

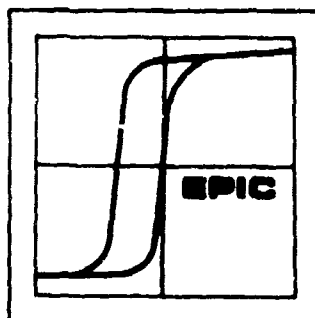


[Ref. 6209]



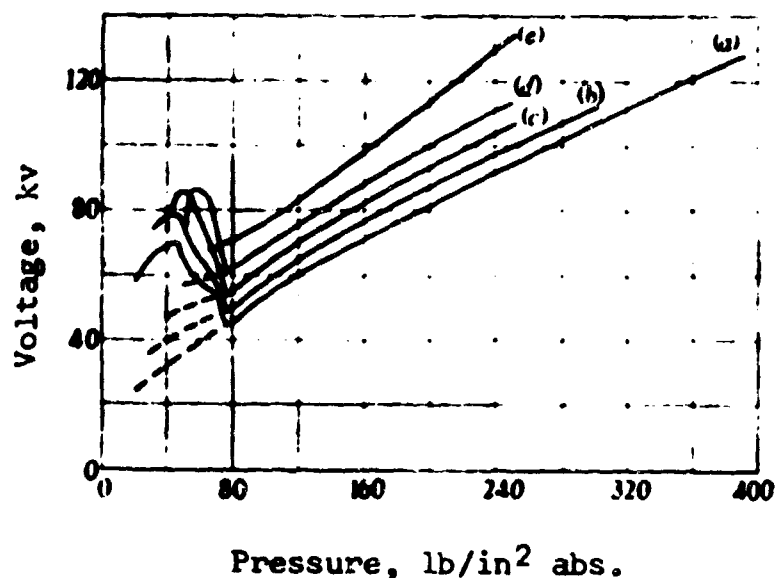
Total breakdown voltage as a function of positive dc bias voltage, 2 atm. absolute pressure at 25°C.

[Ref. 10936]



SULFUR HEXAFLUORIDE

CORONA EFFECTS



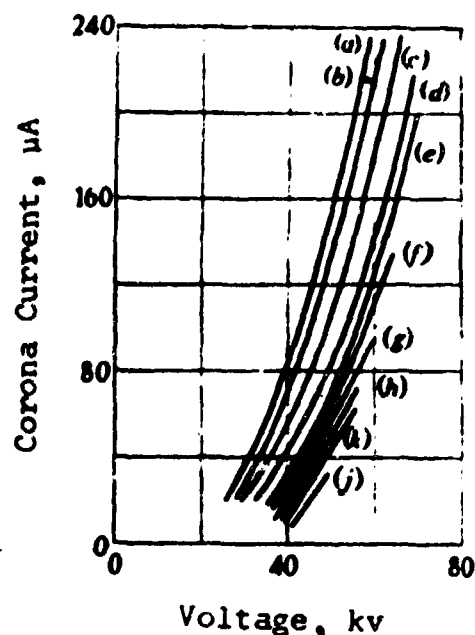
- (a) 20 lb/in² absolute, SF₆ plus N₂
- (b) 30 lb/in² absolute, SF₆ plus N₂
- (c) 40 lb/in² absolute, SF₆ plus N₂
- (d) 50 lb/in² absolute, SF₆ plus N₂
- (e) 65 lb/in² absolute, SF₆ plus N₂

--- Corona onset voltage
— Spark breakdown voltage

Corona onset and spark breakdown characteristics for mixtures of sulfur hexafluoride and nitrogen.

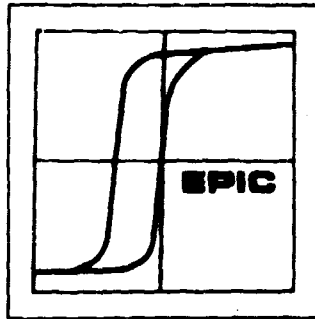
[Ref. 1853]

- (a) Total pressure, 20 lb/in² absolute
- (b) Total pressure, 25 lb/in² absolute
- (c) Total pressure, 30 lb/in² absolute
- (d) Total pressure, 40 lb/in² absolute
- (e) Total pressure, 45 lb/in² absolute
- (f) Total pressure, 50 lb/in² absolute
- (g) Total pressure, 55 lb/in² absolute
- (h) Total pressure, 60 lb/in² absolute
- (i) Total pressure, 65 lb/in² absolute
- (j) Total pressure, 70 lb/in² absolute



Corona current/voltage characteristics for 20 lb/in² sulfur hexafluoride plus nitrogen.

[Ref. 1853]

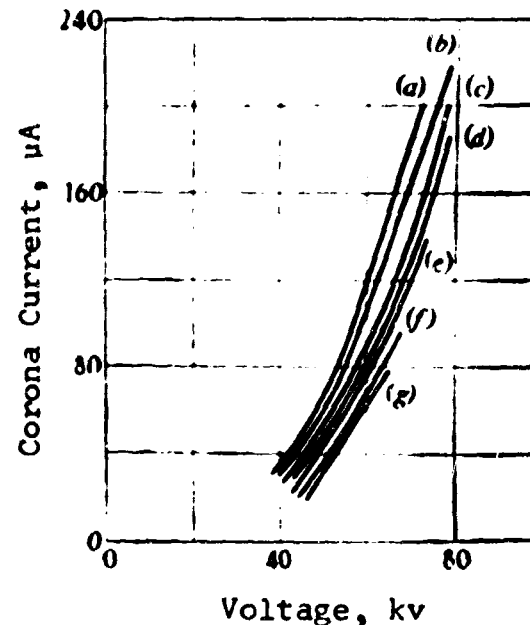


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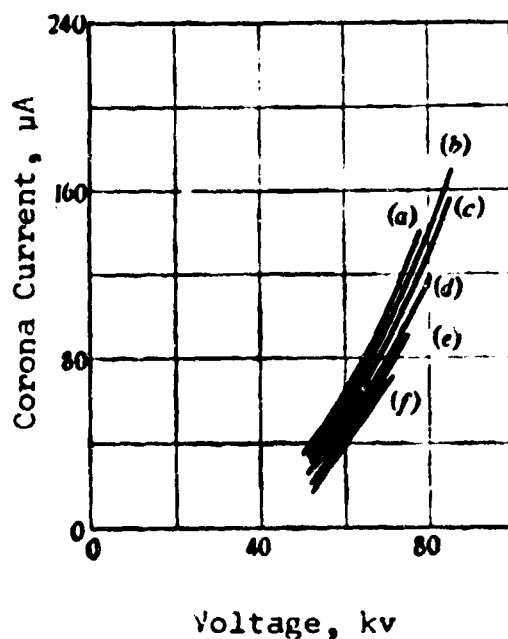
CORONA EFFECTS

Corona current as a function of voltage characteristics for 30 lb/in² sulfur hexafluoride plus nitrogen.

- (a) Total pressure, 30 lb/in² absolute
- (b) Total pressure, 35 lb/in² absolute
- (c) Total pressure, 40 lb/in² absolute
- (d) Total pressure, 45 lb/in² absolute
- (e) Total pressure, 50 lb/in² absolute
- (f) Total pressure, 55 lb/in² absolute
- (g) Total pressure, 60 lb/in² absolute



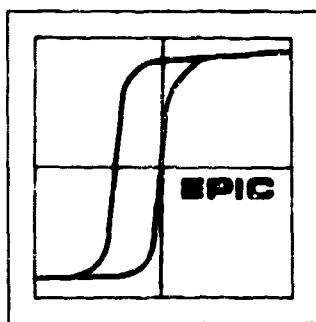
[Ref. 1853]



Corona current as a function of voltage characteristics for 40 lb/in² sulfur hexafluoride plus nitrogen.

- (a) Total pressure, 40 lb/in² absolute
- (b) Total pressure, 45 lb/in² absolute
- (c) Total pressure, 50 lb/in² absolute
- (d) Total pressure, 55 lb/in² absolute
- (e) Total pressure, 60 lb/in² absolute
- (f) Total pressure, 65 lb/in² absolute

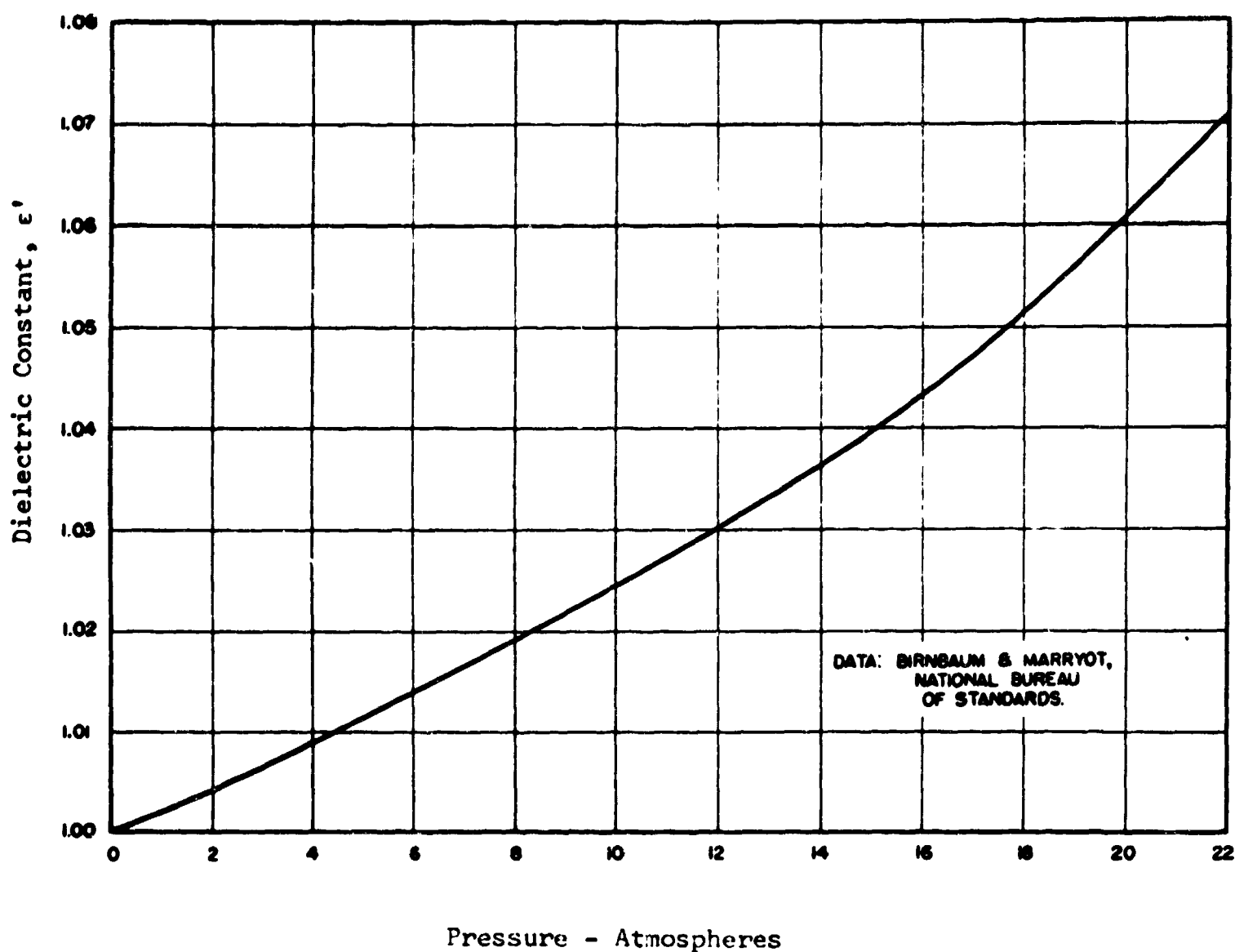
[Ref. 1853]



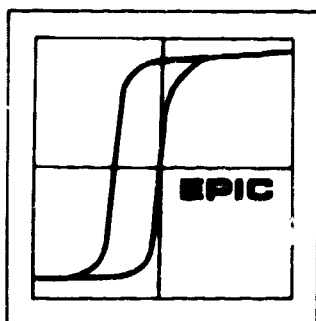
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SULFUR HEXAFLUORIDE

DIELECTRIC CONSTANT



Dielectric constant of sulfur hexafluoride
(25°C and 24,240 μ c) as a function of gas pressure.



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SULFUR HEXAFLUORIDE

DIELECTRIC CONSTANT

Frequency	Pressure	Temperature	Dielectric Constant	Ref.
(10-500kc)	-	27.5°C	1.00191	4299
	760 mm Hg	19.4°C	1.0021	1181
	708 mm Hg	27.5°C	1.00191	11266
	-	-50°C ± 1°C	1.81 ± 0.02	1508
			(liquid SF ₆)	

For other conditions of pressure and temperature the following equation is cited in reference no. 11266.

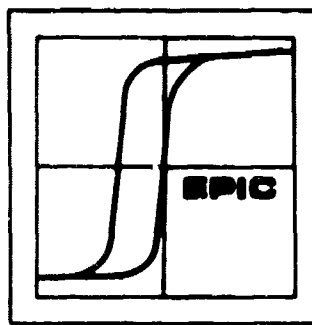
$$\epsilon = 1 + 10^{-6} E$$

where E = dielectric coefficient

For E $\frac{25^{\circ}\text{C}}{0-1}$ = 2049 (limiting value = 0-1 atm.)

For E $\frac{25^{\circ}\text{C}}{0}$ = 2026 (limiting value = 0 atm.:
if gases were perfect)

For E $\frac{-80^{\circ}\text{C}}{0}$ = 2018 (limiting values at -80°C)



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SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(A) Relative Dielectric Strength

Relative Dielectric Strength	Pressure	Temperature
4.5	760 mm Hg	-49.2°C

[Ref. 11279]

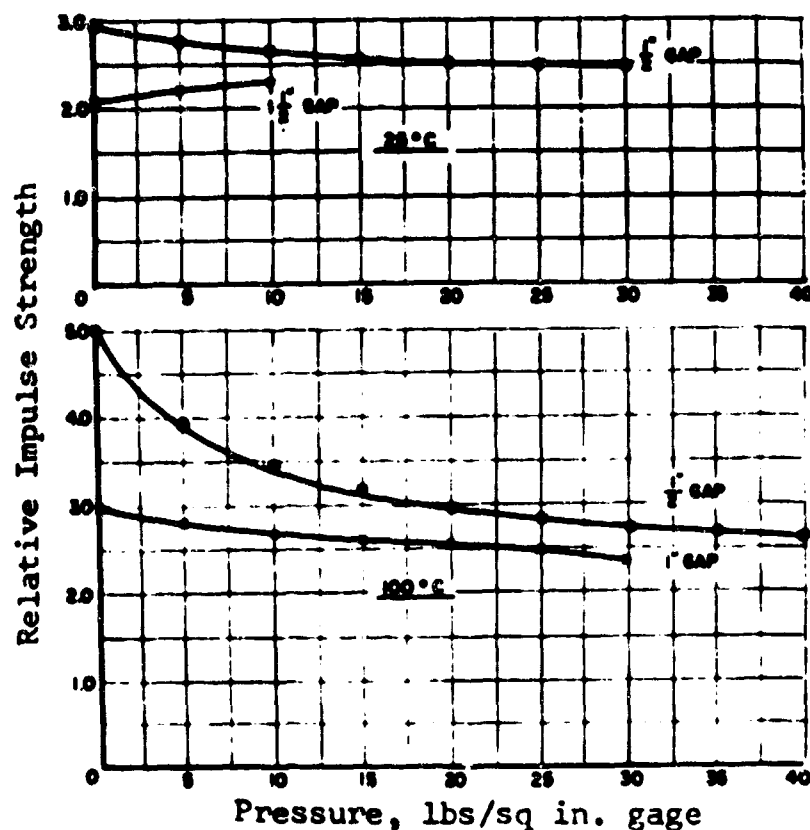
Relative dielectric strength of sulfur hexafluoride (test made between tungsten rod and 1 inch diameter sphere spaced 1-inch.)

Atmospheric Pressure and Room Temperature

Relative Dielectric Strength

Conditions	60 Cycles	Positive	Impulse	Negative
Nonuniform field - 1" spacing SF_6	5	3.5		3.1
Uniform field - 1/4" spacing SF_6	2		1.1	
Looped Toroids - 2" spacing SF_6	1.85	2.4		

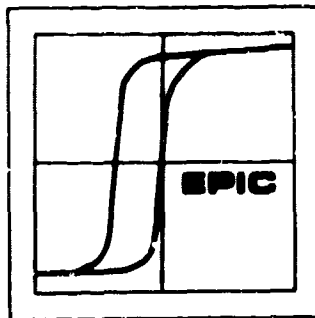
[Ref. 11266]



Relative impulse strength of sulfur hexafluoride and air at both 25 and 100°C as a function of pressure.

Electrodes 0.5 inch stainless steel sphere to 3 inch diameter plane.

[Ref. 11279]

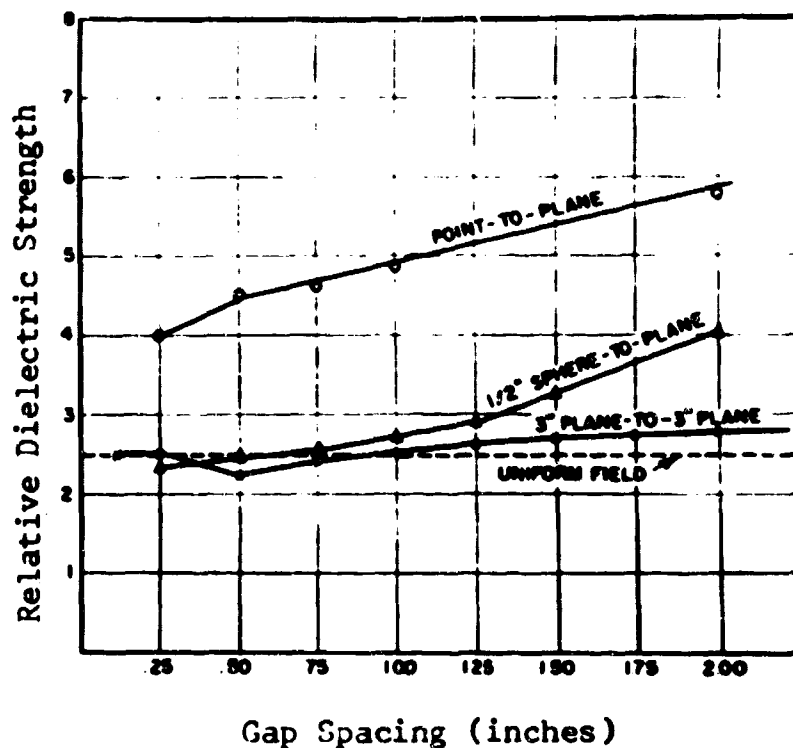


SULFUR HEXAFLUORIDE

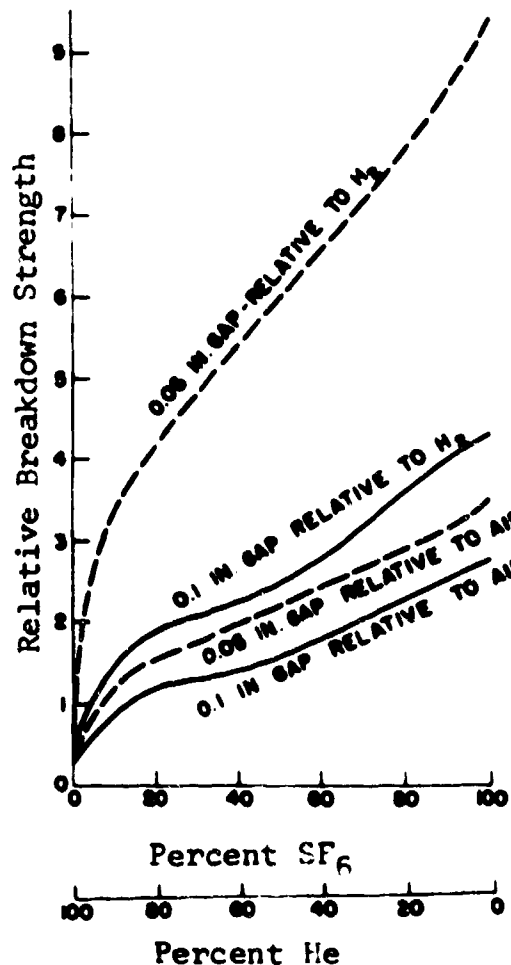
DIELECTRIC STRENGTH

(A) Relative Dielectric Strength

60-cycle relative strength of sulfur hexafluoride to dry air as a function of configuration and spacing of the electrodes. Gases at 25°C and at atmospheric pressure.

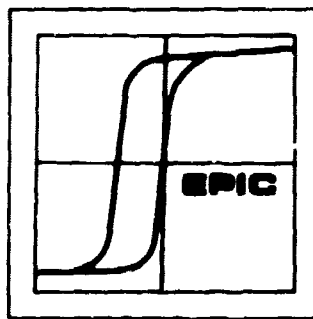


[Ref. 11279]



Relative breakdown strength of mixtures of helium + sulfur hexafluoride.

[Ref. 1931]

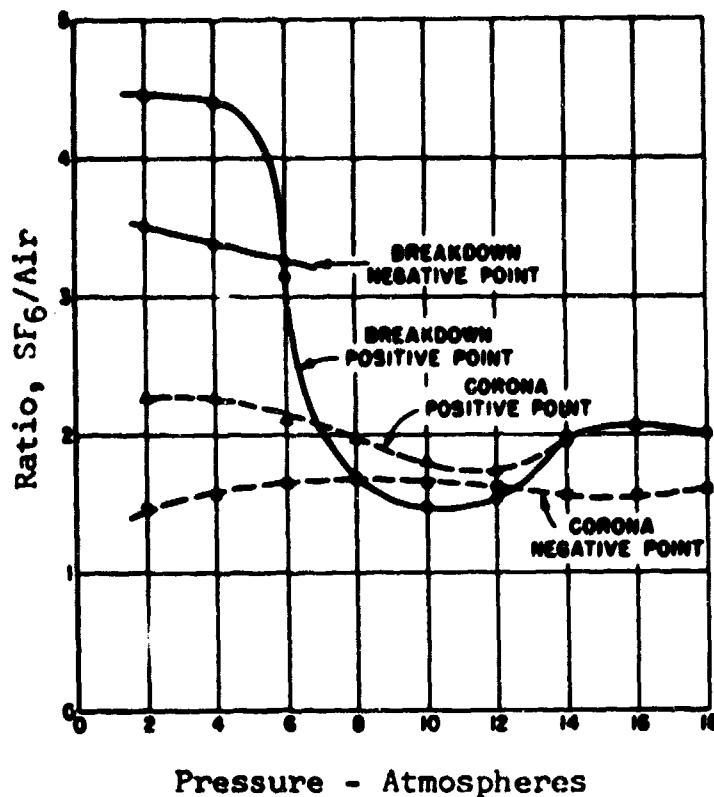


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SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(A) Relative Dielectric Strength

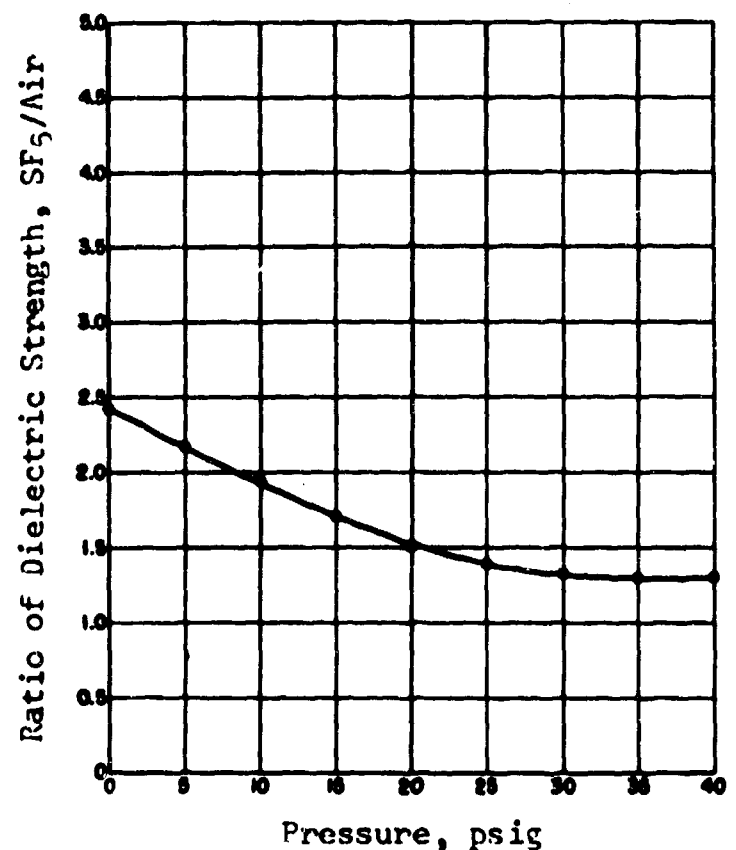


The ratio of the corona and breakdown voltages for air and SF_6 as a function of the testing conditions in a nonuniform field.

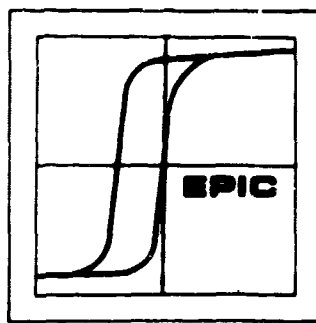
[Ref. 16775]

The changing relation of the impulse voltage breakdown of SF_6 and air as the gas pressure of each is increased.

Electrodes - point-to-plane
Test Gap - 1 1/2 inches
Voltage Wave Form - 1 1/2 x 40 microsec.
Point Electrode Polarity - positive
Test Temperature - 27°C



[Ref. 16775]



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SULFUR HEXAFLUORIDE

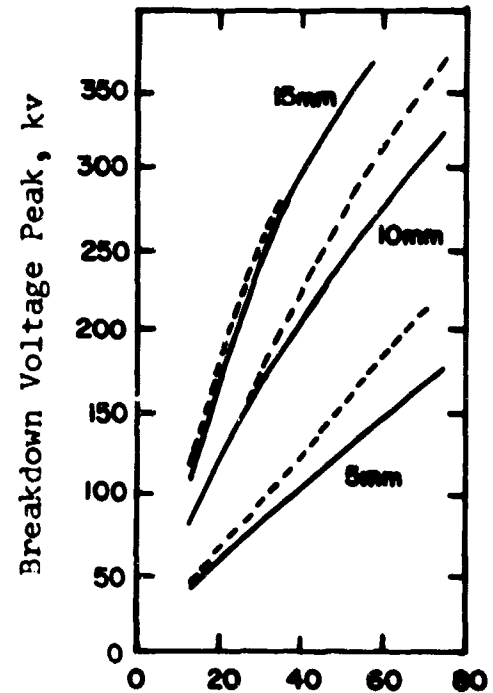
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

(1) Sphere-to-Sphere Geometry

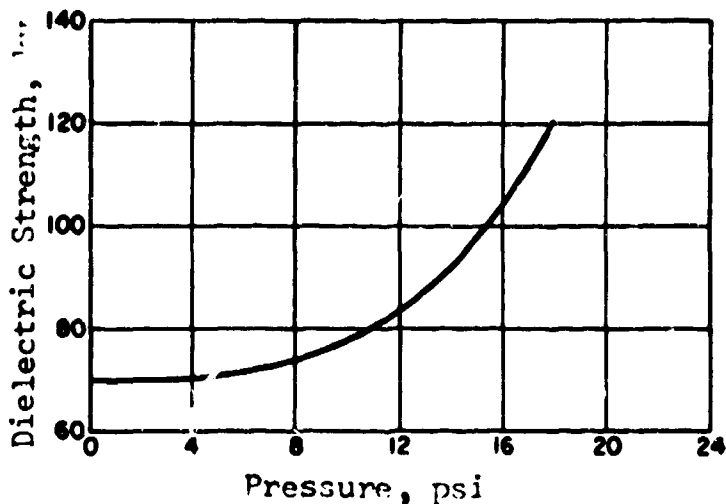
Breakdown voltage between 5 cm diameter spheres
for sulfur hexafluoride.

---- Negative impulse
— Power Frequency



Gas Pressure, lb/in² (abs.)

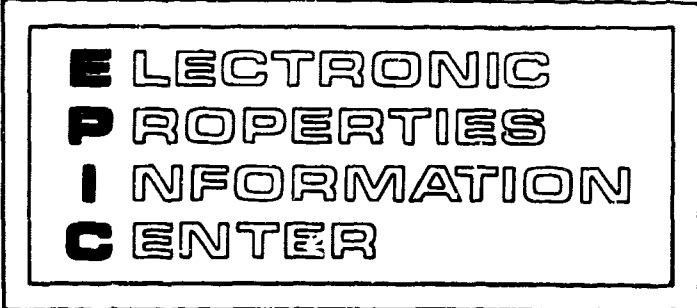
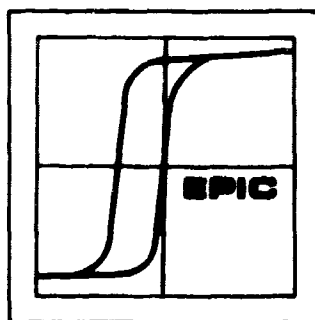
[Ref. 1589]



Electrodes - 1 inch spheres
Gap Distance - 1/4 inch
Temperature - room
Pressure - atmospheric

The dielectric strength of sulfur hexafluoride gas measured by impulse voltage in a uniform electrical field.

[Ref. 16775]



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SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

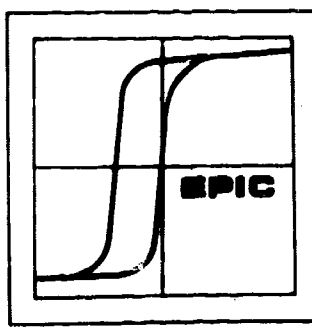
(1) Sphere-to-Sphere Geometry

Breakdown data for sulfur hexafluoride (5-cm diameter spherical electrodes).

Breakdown Voltage, (kv)

Com- pound	Absolute Pressure Atm.	Power Frequency		Negative direct		Negative impulse		Relative electric strength		Impulse ratio	
SF ₆	1 2 3 4	Sphere gap, cm									
		0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
		45.0	86.0	44.0	83.5	47.7	91.3	2.6	2.7	1.06	1.06
		79.0	161.0			91.0	171.0	2.47	2.87	1.15	1.06
		112.5	218.0			134.5	244.0	2.48	2.68	1.19	1.12
		143.5	268.0			175.0	309.0	2.47	2.53	1.22	1.15

[Ref. 1181]



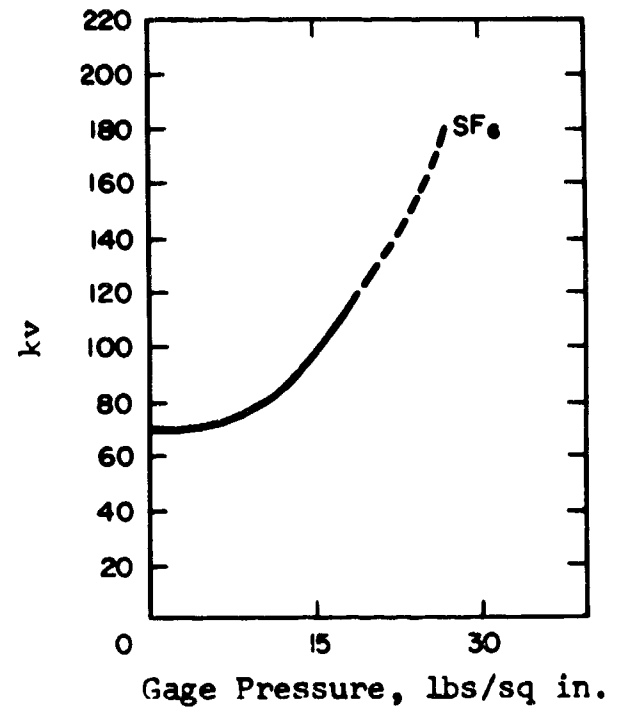
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

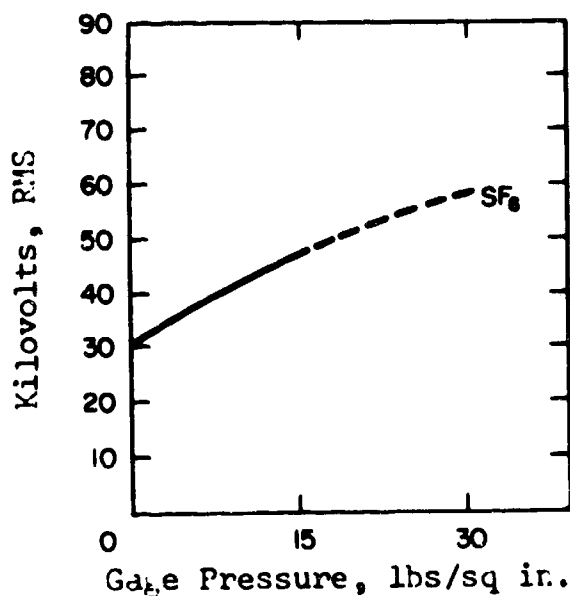
(B) Dielectric Strength vs Pressure

(1) Sphere-to-Sphere Geometry

Impulse dielectric strength voltages of SF_6 using two 1-inch diameter spheres.

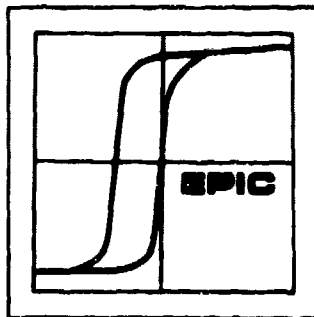


[Ref. 4299]



60-cycle dielectric strength of SF_6 tested between two 1-inch diameter spheres spaced 1/4 inch and at a gage pressure up to 30 psi.

[Ref. 4299]



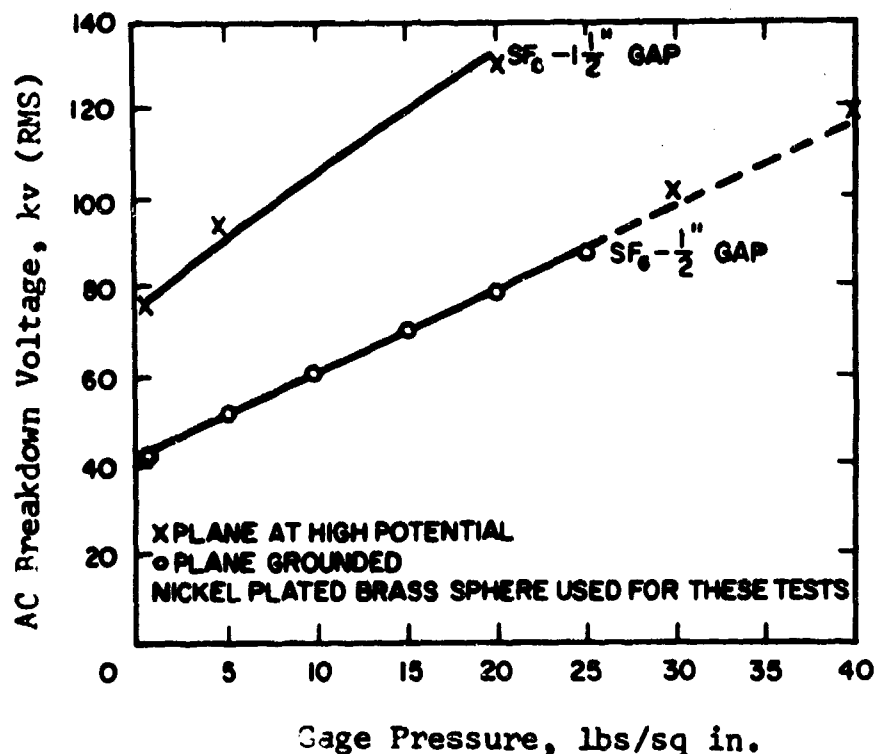
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

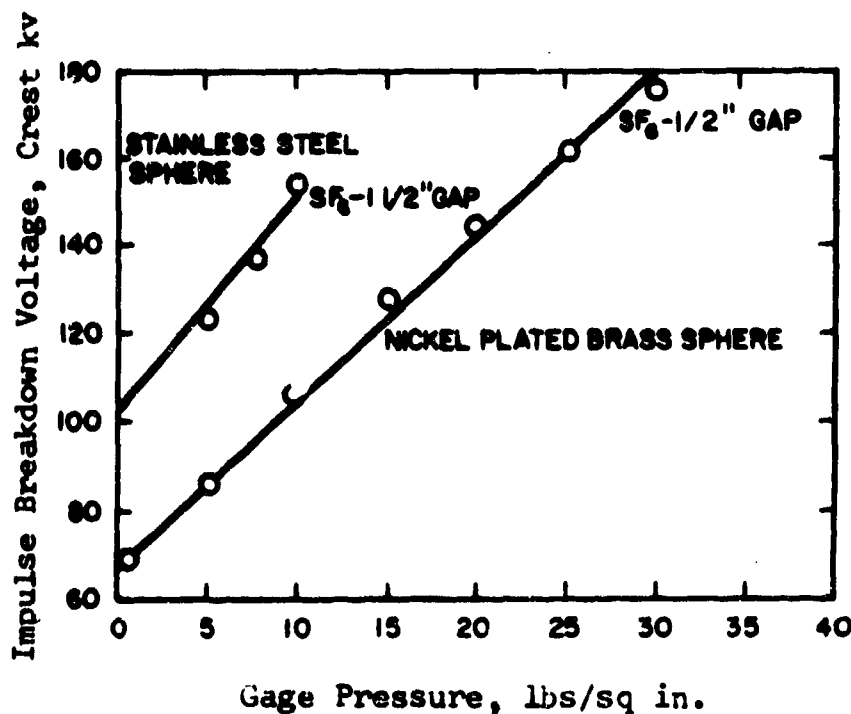
(B) Dielectric Strength vs Pressure

(2) Sphere-to-Plane Geometry

60-cycle breakdown voltages of SF_6 as a function of pressure. (Gas at room temperature.) Electrodes 0.5 inch diameter sphere to 3 inch diameter plane.

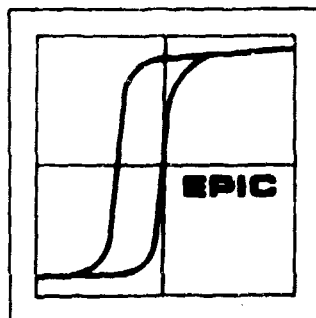


[Ref. 11279]



Impulse breakdown of SF_6 at room temperature as a function of pressure. Electrodes 0.5 inch sphere to 3 inch diameter plane. Positive impulse wave 1 1/2 by 40 microseconds.

[Ref. 11279]



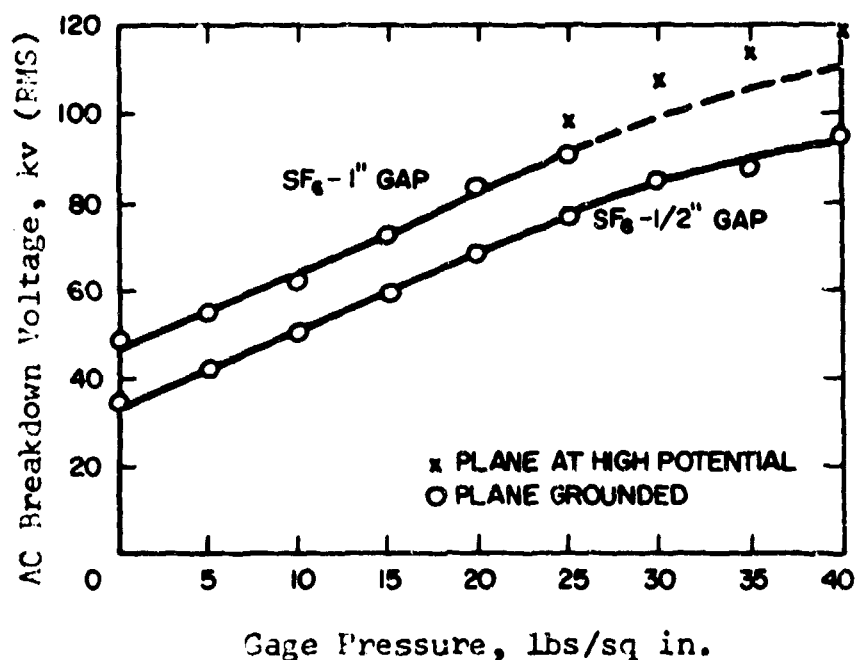
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

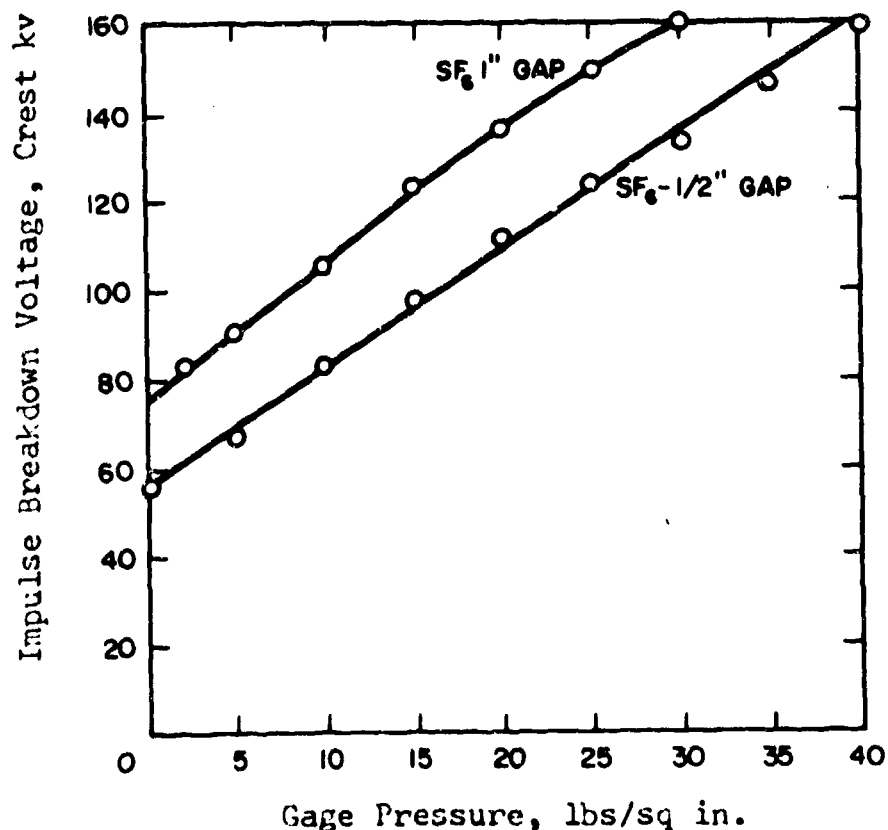
(B) Dielectric Strength vs Pressure

(2) Sphere-to-Plane Geometry

60-cycle breakdown voltages of SF_6 at $100^\circ C$ as a function of pressure. Electrodes 0.5 inch stainless steel sphere to 3 inch diameter point.

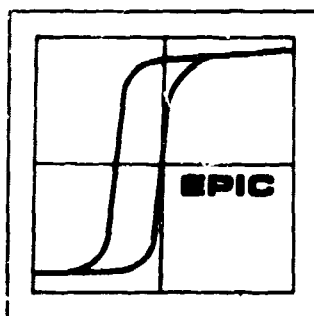


[Ref. 11279]



Impulse breakdown voltages of SF_6 at $100^\circ C$ as a function of pressure. Electrodes 0.5 inch stainless steel sphere to 3 inch diameter plane. Positive impulse wave 1 1/2 by 40 microseconds.

[Ref. 11279]

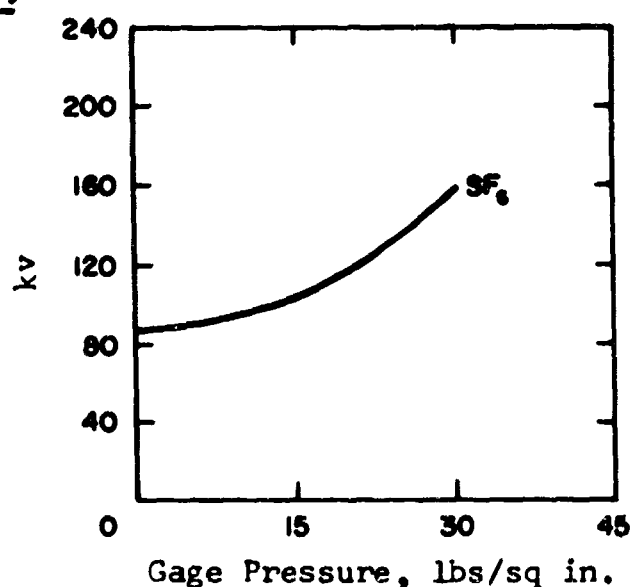


SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

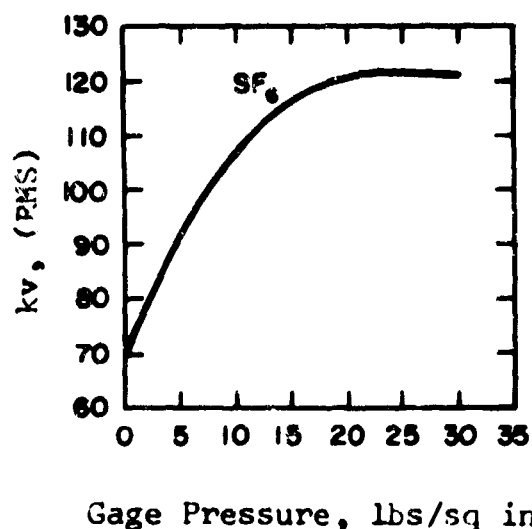
(B) Dielectric Strength vs Pressure

(3) Sphere-to-Rod Geometry



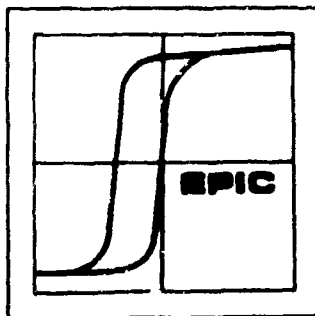
Impulse dielectric strength of SF_6 as a function of pressure. Positive-wave tests made between tungsten rod and 1 inch diameter sphere spaced 1 inch.

[Ref. 4299]



60-cycle dielectric strength of SF_6 as a function of pressure. Tests made between tungsten rod and 1 inch sphere spaced 1 inch.

[Ref. 4299]



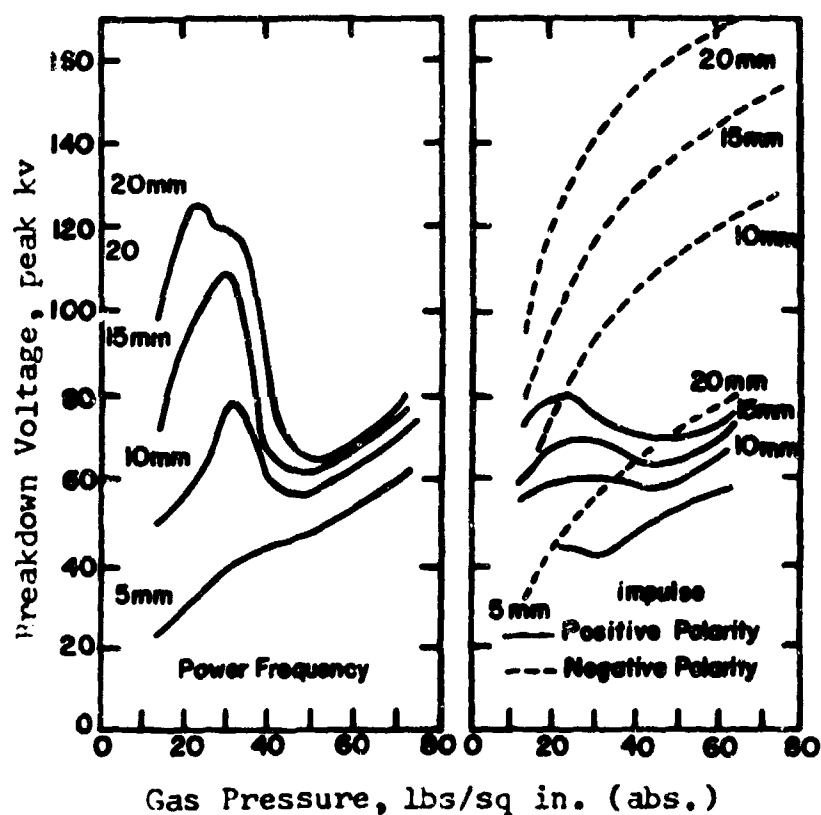
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

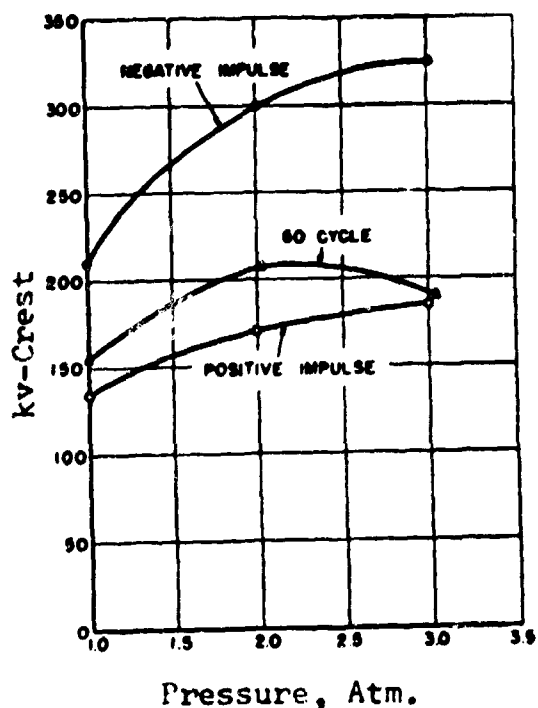
(B) Dielectric strength vs Pressure

(4) Sphere-to-Point Geometry

Breakdown voltage characteristics with point-sphere electrodes for SF₆.

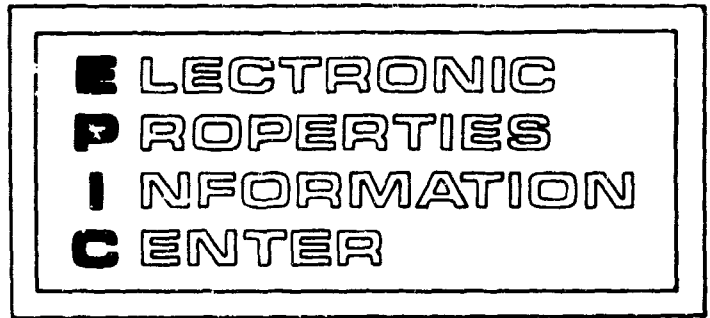
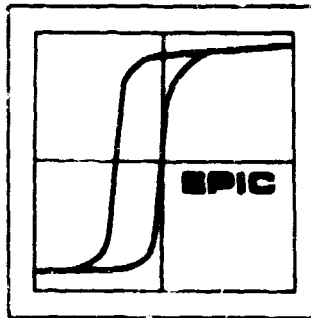


[Ref. 1589]



Dielectric strength of a 2 inch gap-point to 1 inch diameter sphere as a function of pressure.

[Ref. 11279]



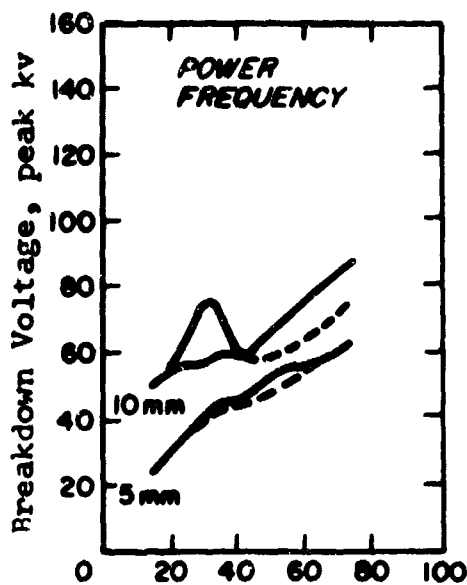
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SULFUR HEXAFLUORIDE

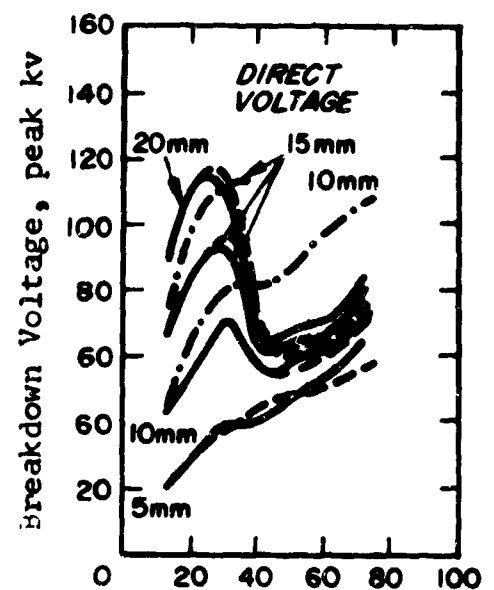
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

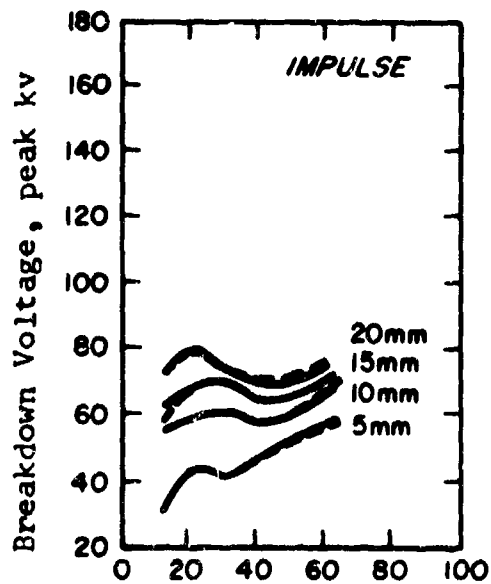
(4) Sphere-to-Point Geometry



Gas Pressure, lbs/sq in.
(abs.)



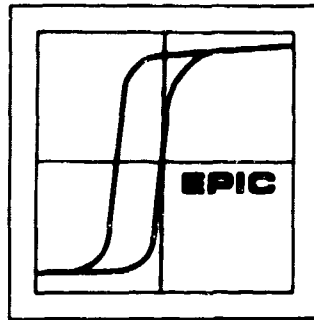
Gas Pressure, lbs/sq in.
(abs.)



Gas Pressure, lbs/sq in.
(abs.)

Breakdown voltage for sulfur hexafluoride with point-sphere electrodes.

- Power frequency, positive d.c. and impulse
- - - Negative d.c. and impulse
- . - Positive d.c. and impulse with radium.



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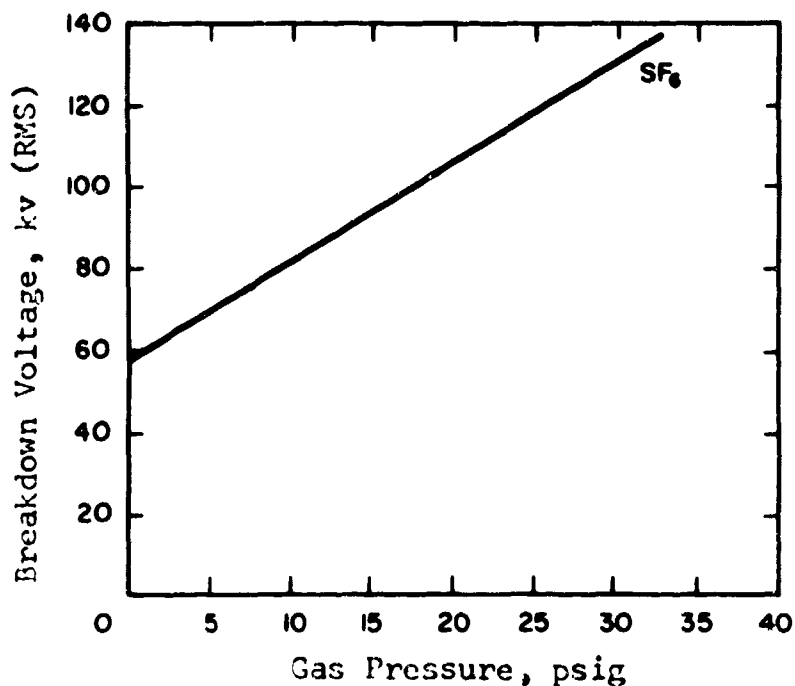
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

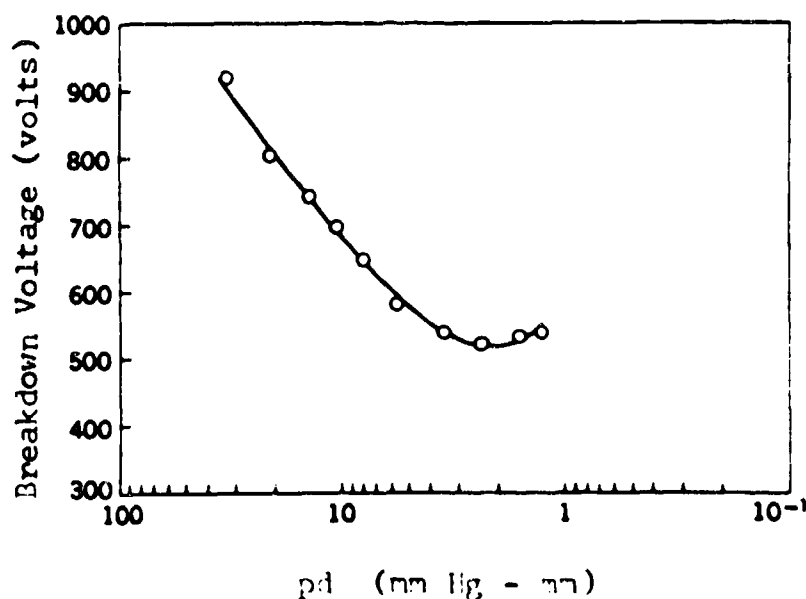
(B) Dielectric Strength vs Pressure

(5) Plane-to-Plane Geometry

Dielectric strength of sulfur hexafluoride as a function of pressure, 3 inch diameter round-edged plane-to-plane, 1/2 inch spacing.

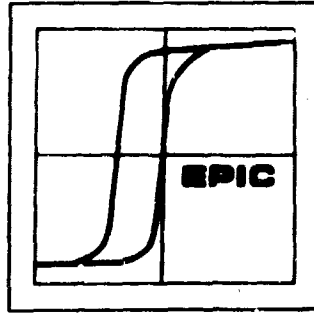


[Ref. 10452]



Paschen curve for sulfur hexafluoride (gap 1 mm, parallel circular brass plates, 4 inches in diameter and 1/4 inch thick with rounded edges of 1/8 inch radius.)

[Ref. 16238]

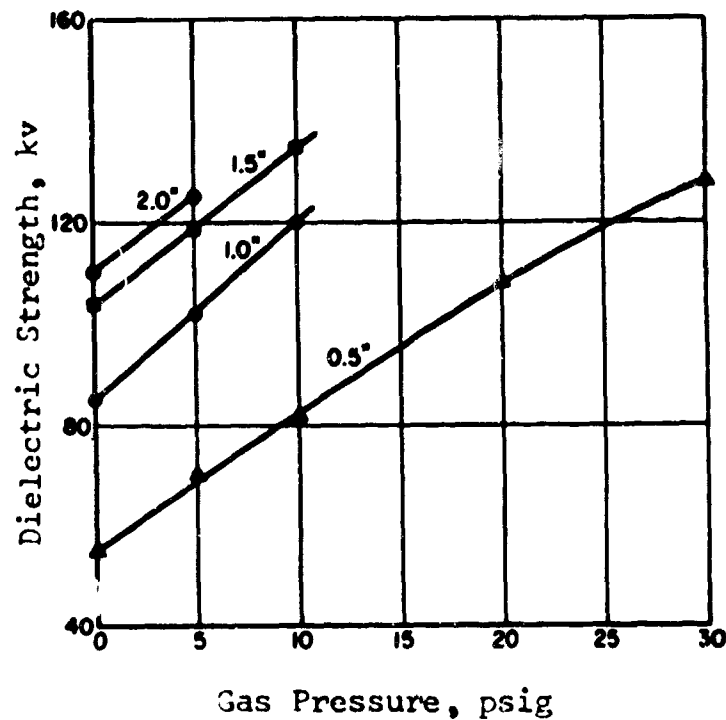


SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

(5) Plane-to-Plane Geometry



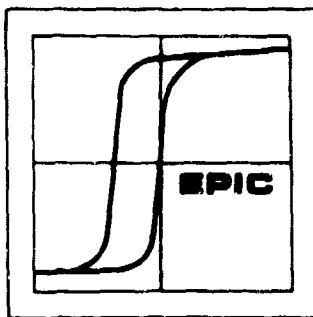
The dielectric strength-pressure relation for sulfur hexafluoride gas, showing the effect of gap distance.

Electrodes - 3" diameter, rounded edge planes

Test temperature - room

Gap Distance - inches as shown on each curve

[Ref. 16775]

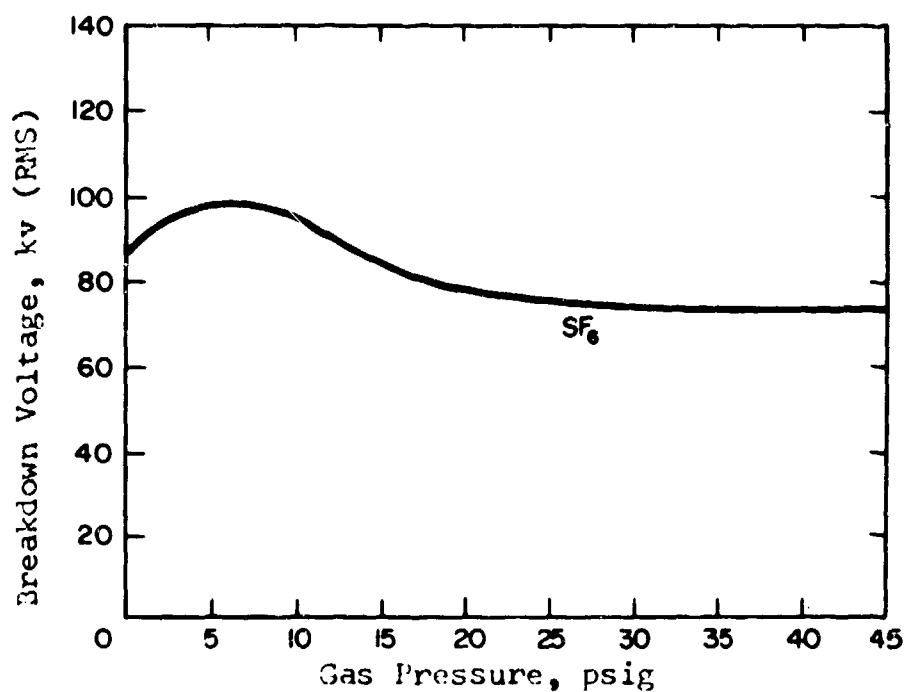


SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

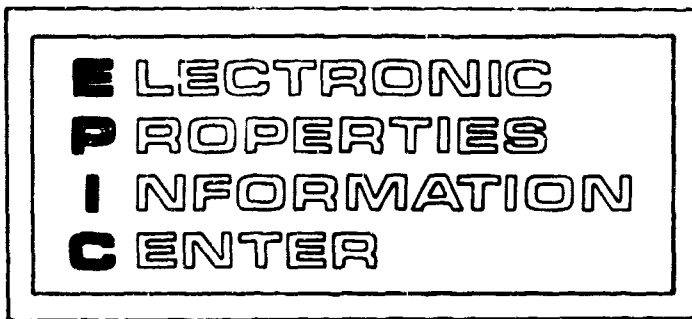
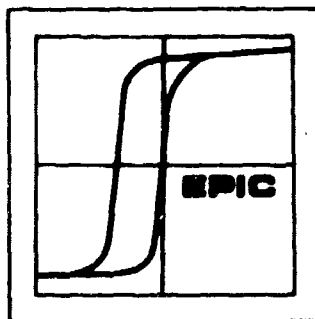
(E) Dielectric Strength vs Pressure

(6) Plane-to-Rod Geometry



Dielectric strength of sulfur hexafluoride as a function of pressure.
1/4 inch square rod-to-plane, 1 inch spacing.

[Ref. 10452]



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SULFUR HEXAFLUORIDE

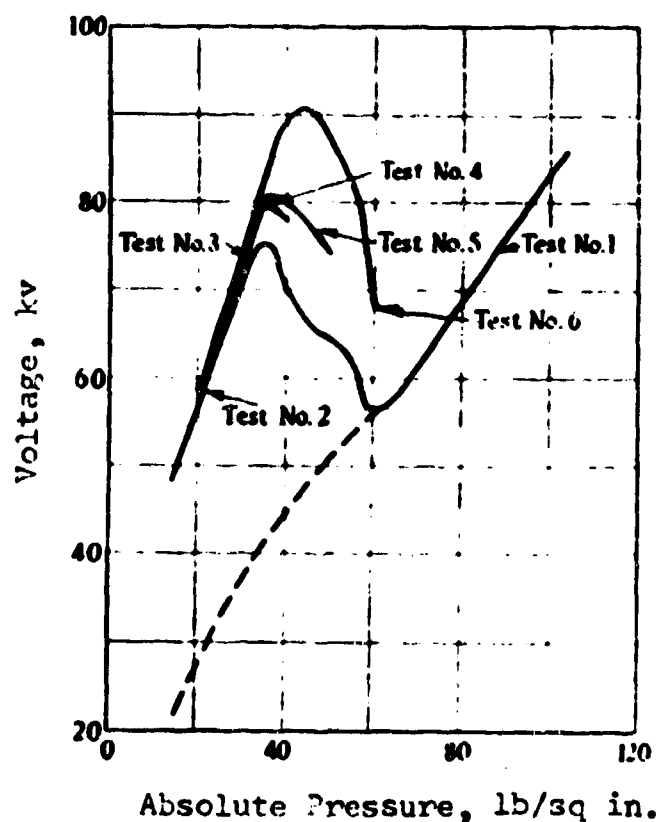
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

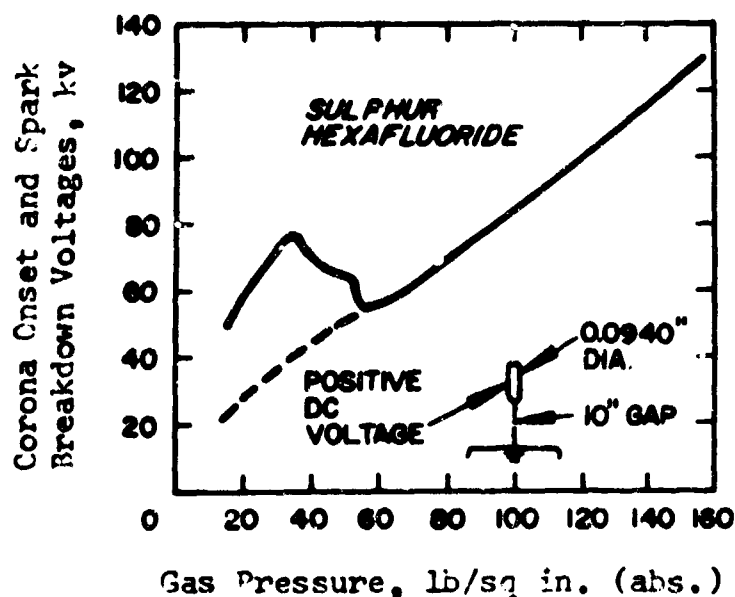
(7) Plane-to-Point Geometry

Corona onset and spark-breakdown characteristics for sulfur hexafluoride.

- Corona onset voltage
- Spark-breakdown voltage

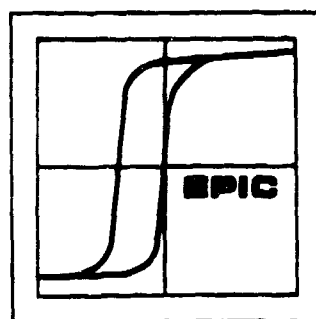


[Ref. 1853]



Spark breakdown voltage of sulfur hexafluoride as a function of pressure.

[Ref. 1655]



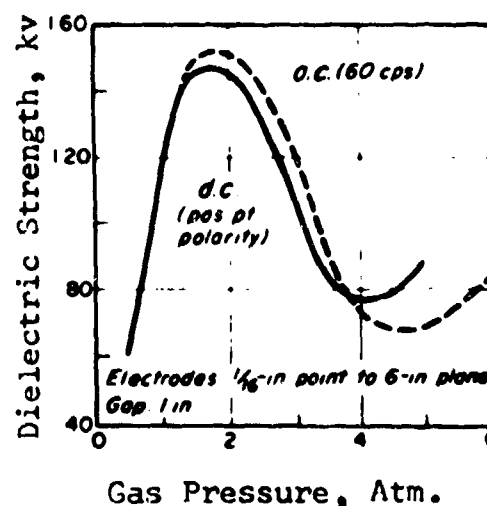
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

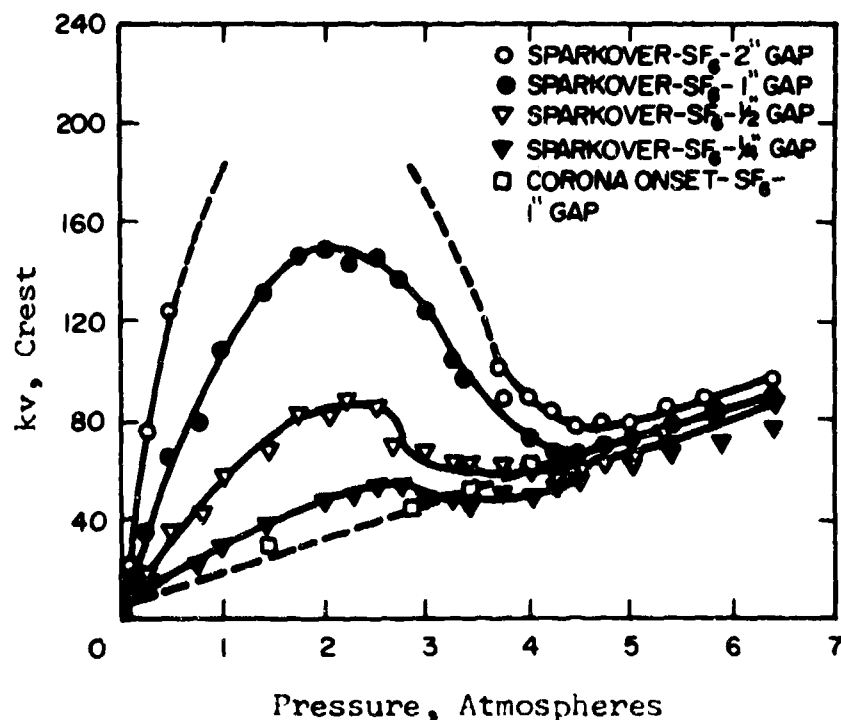
(B) Dielectric Strength vs Pressure

(7) Plane-to-Point Geometry

Gas pressure as a function of dielectric strength for d.c. and 60 cps a.c. voltage. Dielectric strength increases normally with pressure up to about 1 atm. Further increase in pressure produces a divergence from the straight line until a maximum strength is reached at about 2 atm. Increasing pressure beyond this point results in a drop in strength, the minimum occurring at about 5 atm.

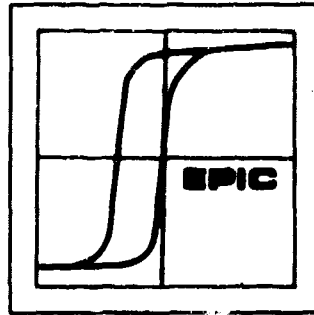


[Ref. 6140]
and
[Ref. 16775]



a.c. spark-over and corona onset voltages of sulfur hexafluoride for indicated gaps between 1/16 inch hemisphere point and 6 inch diameter plane in 12 inch diameter steel tank as a function of pressure.

[Ref. 11302]



SULFUR HEXAFLUORIDE

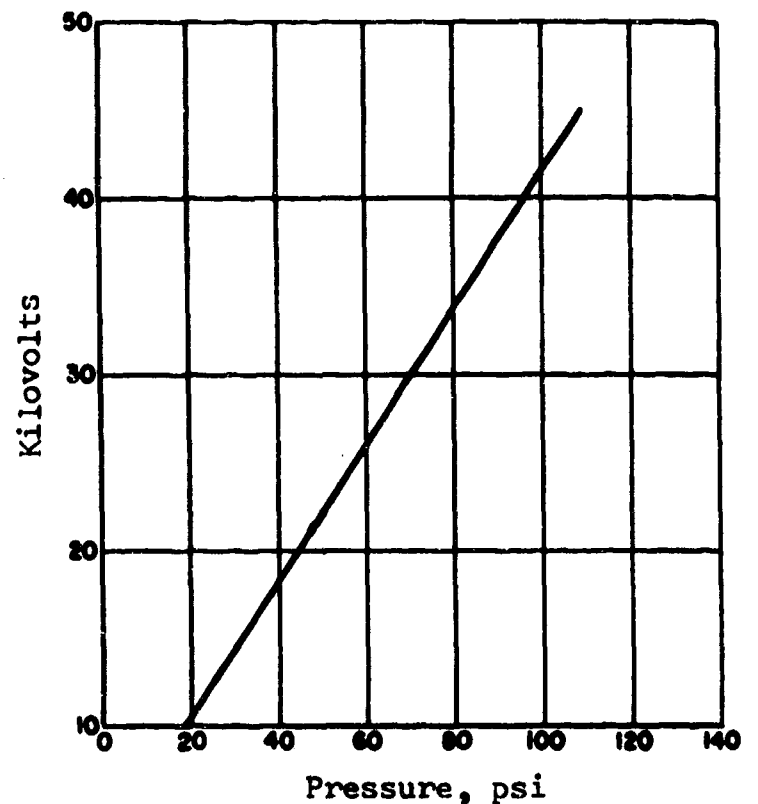
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

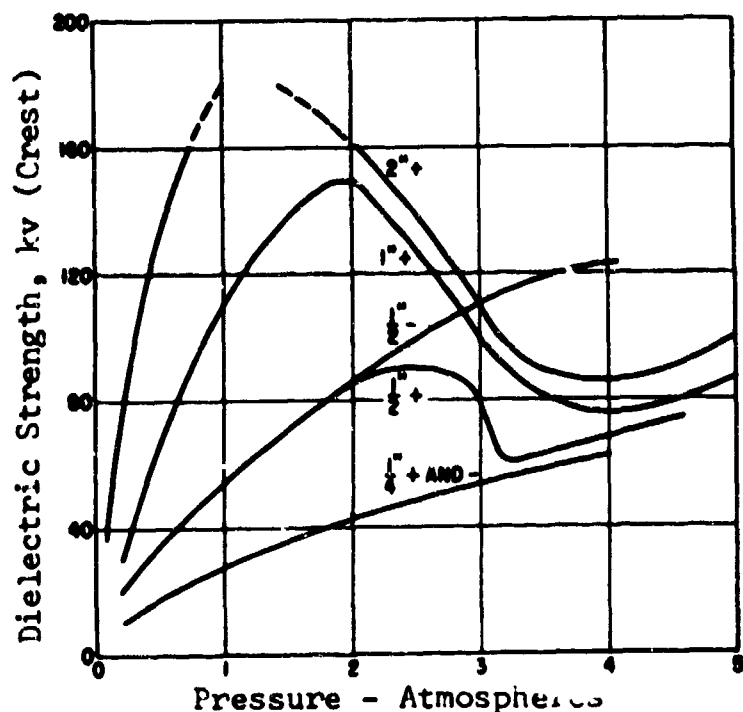
(7) Plane-to-Point Geometry

The effect of gas pressure on the voltage necessary to cause a prebreakdown current of 20 micro amperes in sulfur hexafluoride gas at room temperature.

Gap distance - 3 mm (0.118 inches)
Electrodes - point-to-plane
Electrode Point - positive polarity



[Ref. 16775]

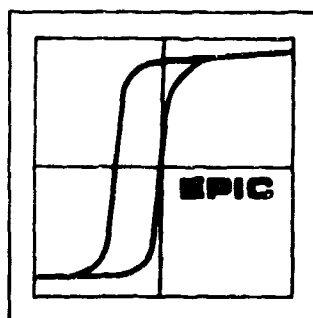


The effect of pressure on the dielectric strength of sulfur hexafluoride gas in a nonuniform (DC) electrical field for selected gap distances.

Electrodes - 1/16" point to 6" plane
Electrode Polarity - point electrode as shown

Gap Distance - as shown on curve

[Ref. 16775]

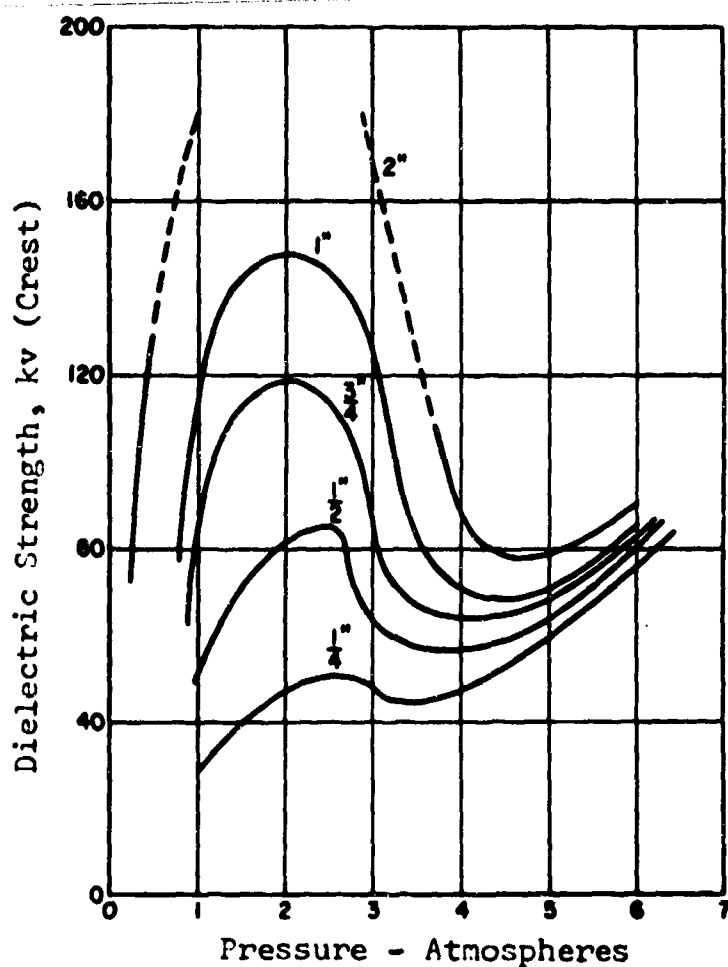


SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

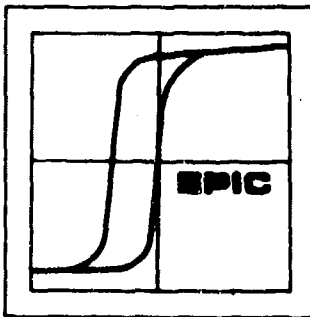
(B) Dielectric Strength vs Pressure

(7) Plane-to-Point Geometry



The effect of pressure on the 60 cycle breakdown of sulfur hexafluoride gas at selected gap distances.

Electrodes - 1/16" point to 6" plane
Gap Distance - as shown on curve



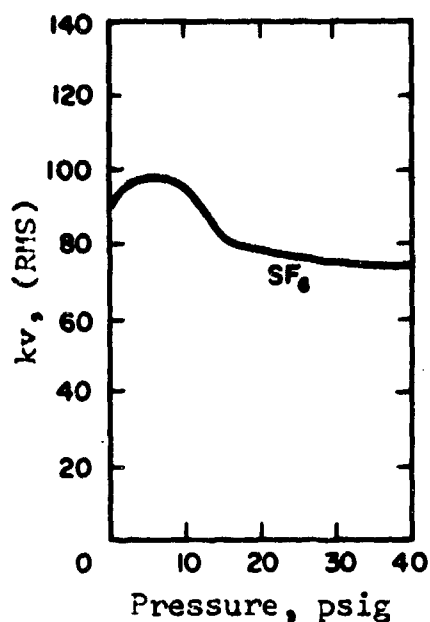
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

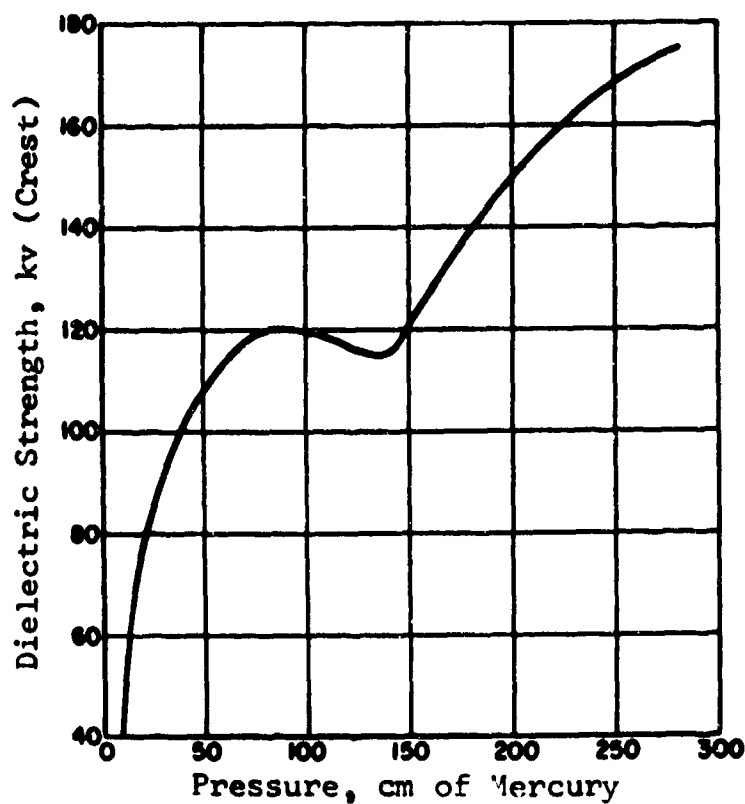
(9) Dielectric Strength vs Pressure

(8) Rod-to-Rod Geometry

Breakdown voltage, nonuniform field,
1/4" rod.



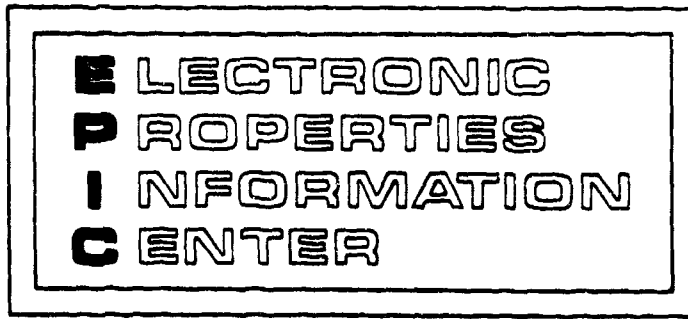
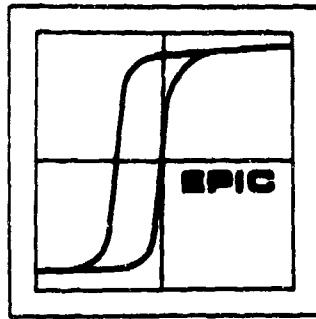
[Ref. 1860]



The impulse breakdown of sulfur hexafluoride gas as affected by pressure.

Electrodes - 1/2" square cut rods
Gap Distance - 2 inches
Voltage Form - 1 1/2 x 40 microsec.
Voltage Polarity - positive

[Ref. 16775]



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SULFUR HEXAFLUORIDE

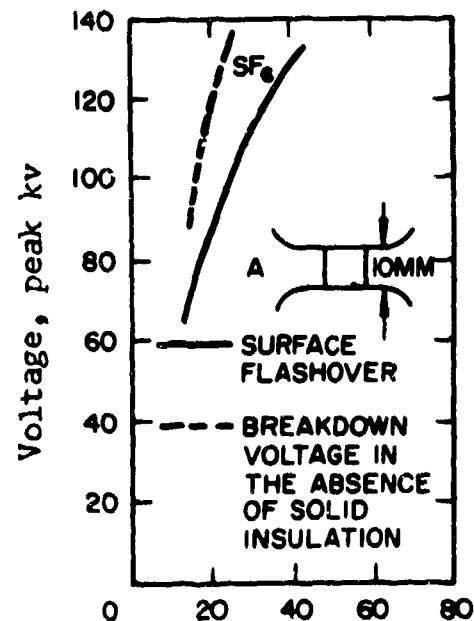
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

(9) Miscellaneous Geometries

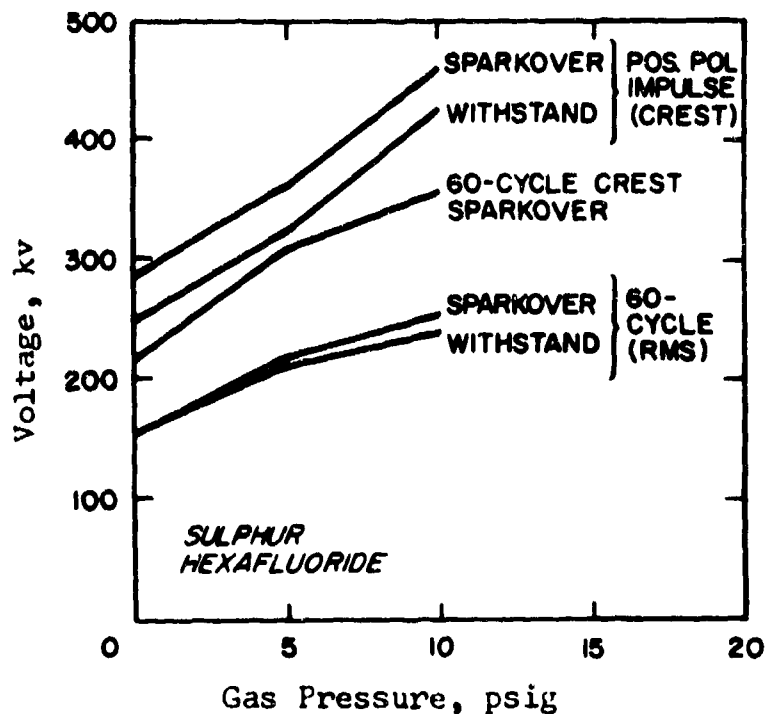
Power frequency flashover voltage of solid insulation in sulfur hexafluoride. Uniform tangential stress.

- Breakdown voltage in the absence of solid insulation
- Surface flashover



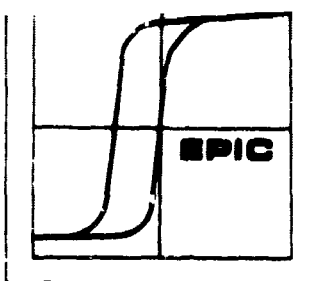
Gas Pressure, lb/sq in. (abs.)

[Ref. 1589]



Impulse and 60 cycle sparkover and withstand voltages of sulfur hexafluoride using 2 inch gap spacing.

[Ref. 4299]



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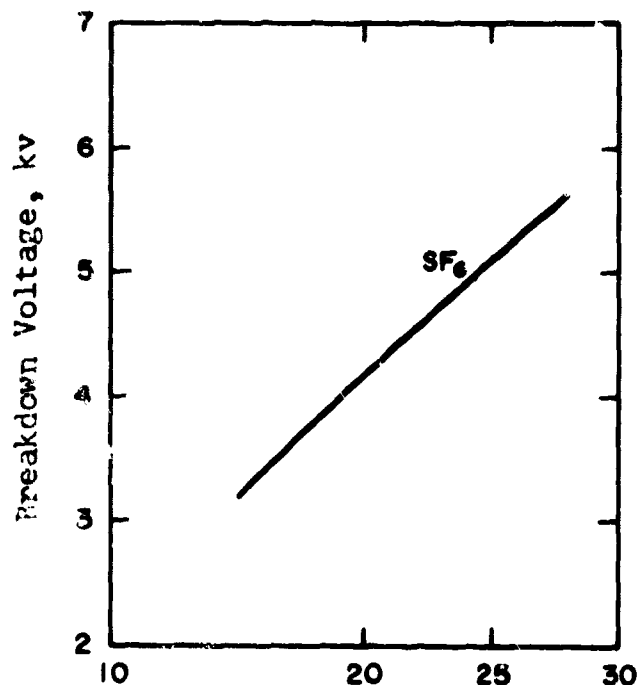
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

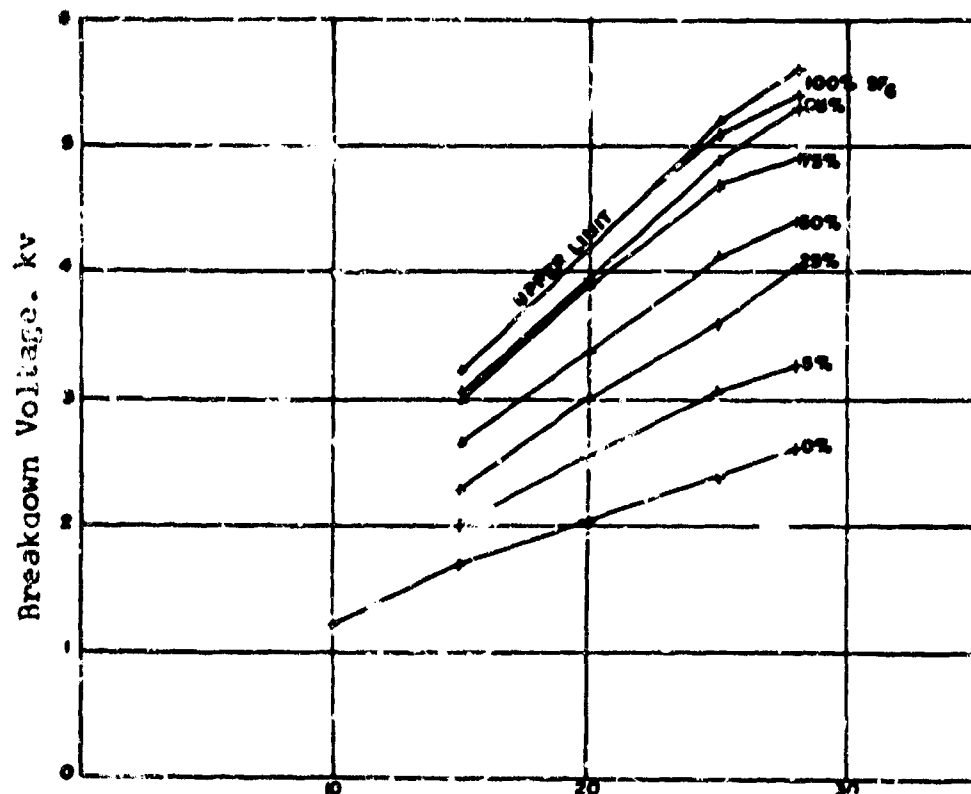
(9) Miscellaneous Geometries

Breakdown voltage as a function of pressure for SF_6 (across a spark-plug.)



Pressure in Inches, Hg (abs.)

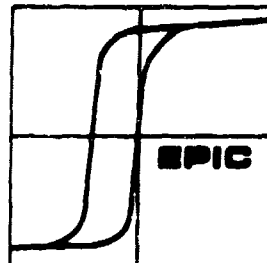
[Ref. 10489]



Pressure in Inches, Hg (abs.)

Breakdown voltage of mixtures of SF_6 and air as a function of pressure abs. 60 cps a-c applied across a sparkplug.

[Ref. 10002]



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SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

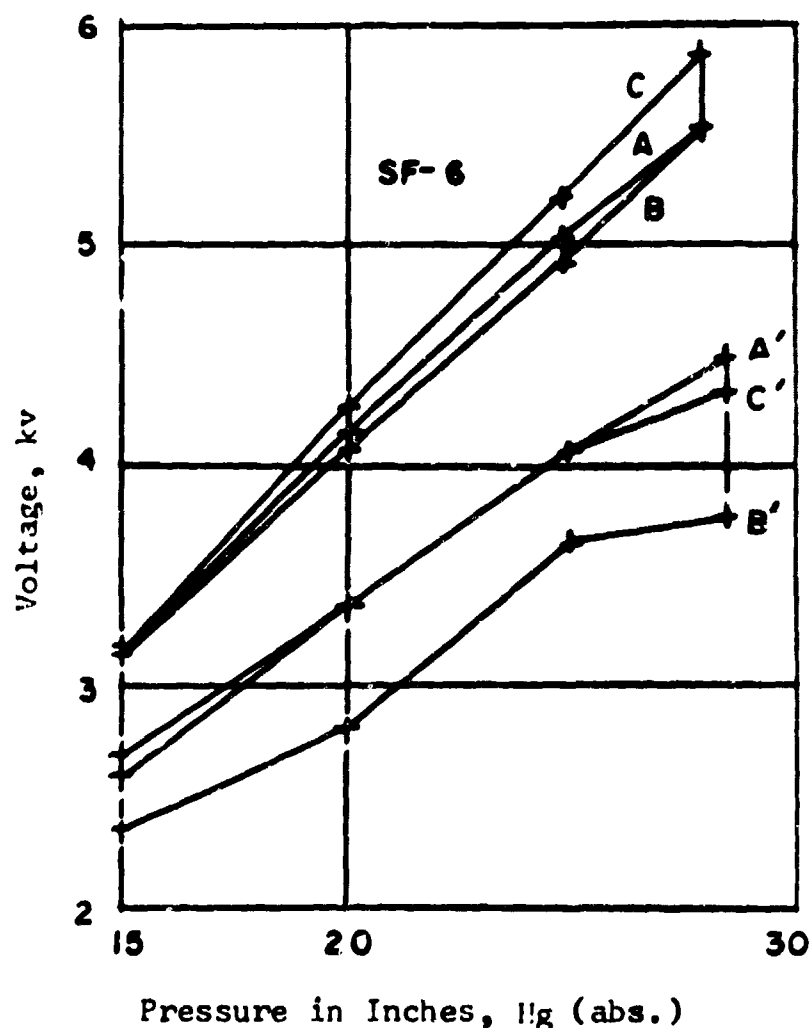
(9) Miscellaneous Geometries

A,B,C - occur in chronological order

- A - initial breakdown onset voltage
- B - voltage necessary to extinguish arc after 1 minute of continuous arcing in confined volume
- C - onset voltage for breakdown after 1 minute continuous arcing in confined volume, followed by extinguishing

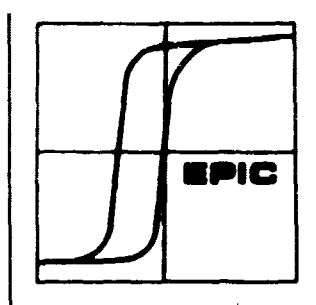
A,B,C - for dielectric gas as received from the manufacturer

A',B',C' - for 50% dielectric gas and 50% air mixture



Breakdown voltage, extinguish voltage as a function of pressure.

[Ref. 10002]

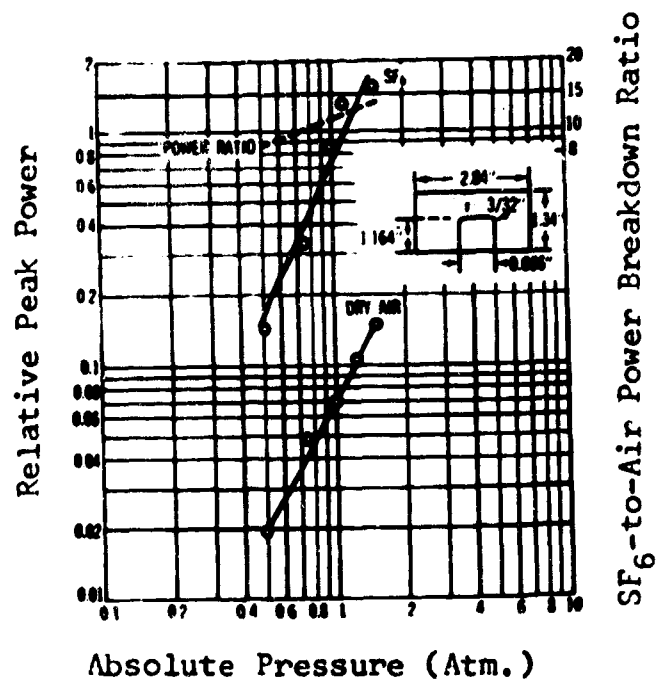
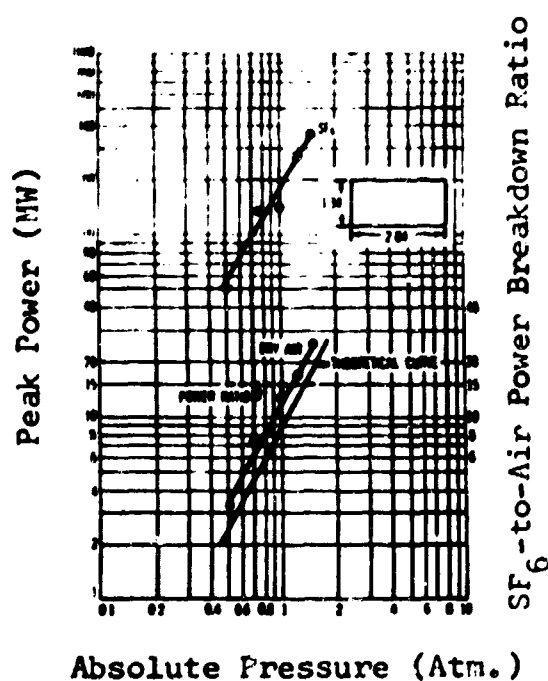


SULFUR HEXAFLUORIDE

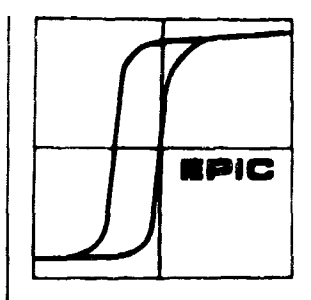
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

(9) Miscellaneous Geometries



RG-49U Waveguide (plane-to-plane configuration, left) - frequency, 2773 mc; cavity loaded Q, 159.5; PRF, 225 pps; pulse length, two microseconds. Single Ridge-to-plane S-Band Configuration (right) - frequency, 2812 mc; cavity loaded Q, 165; PRF, 225 pps; pulse length, two microseconds; cross-section drawing not to scale. Diffusion and ion pair recombination have decisive effect on breakdown phenomena. Both depend on electrode configuration and spacing. Pressure and ionic nature of gas under test also affect results.



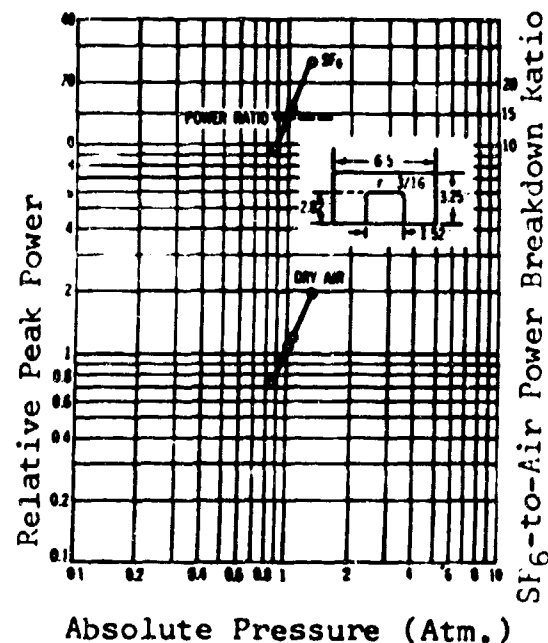
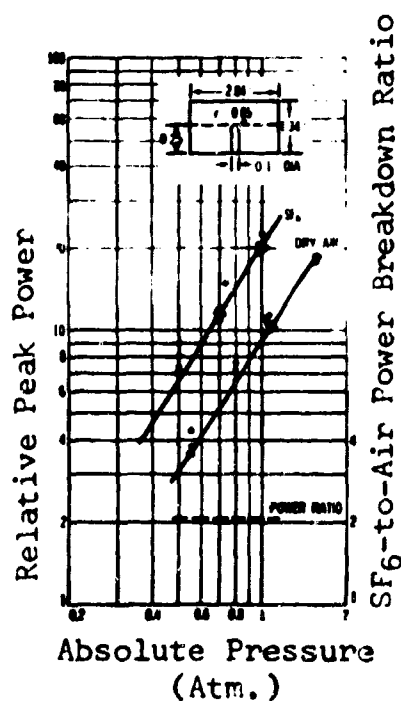
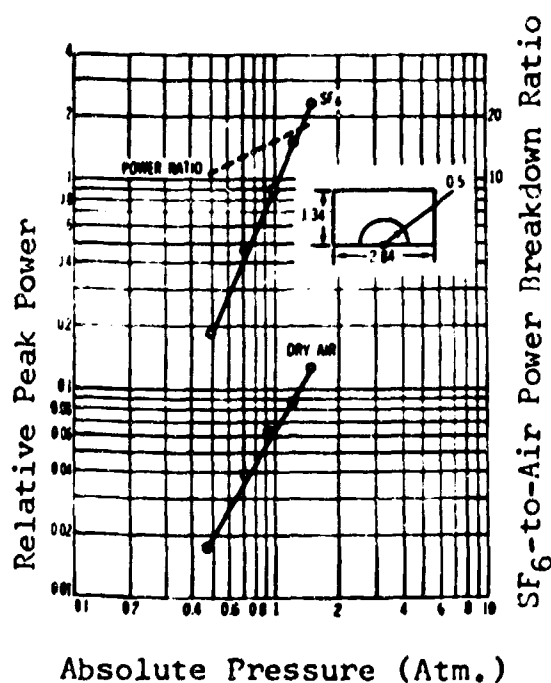
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SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

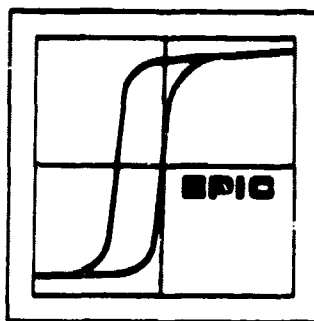
(B) Dielectric Strength vs Pressure

(9) Miscellaneous Geometries



Hemisphere-to-Plane S-Band Configuration (left) - Frequency, 2757 mc; cavity loaded Q, 131; PRF, 225 pps; pulse length, two microseconds; cross-section drawing not to scale. Center: Rounded-Point-to-Plane S-Band Configuration - frequency, 2752 mc; PRF, 225 pps; pulse length, two microseconds; cross-section drawing not to scale. Right: Single-Ridge-to-Plane L-Band Configuration - frequency, 1316.5 mc; cavity loaded Q, 222; PRF, 360 pps; pulse length, six microseconds; cross-section drawing not to scale.

[Ref. 6221]



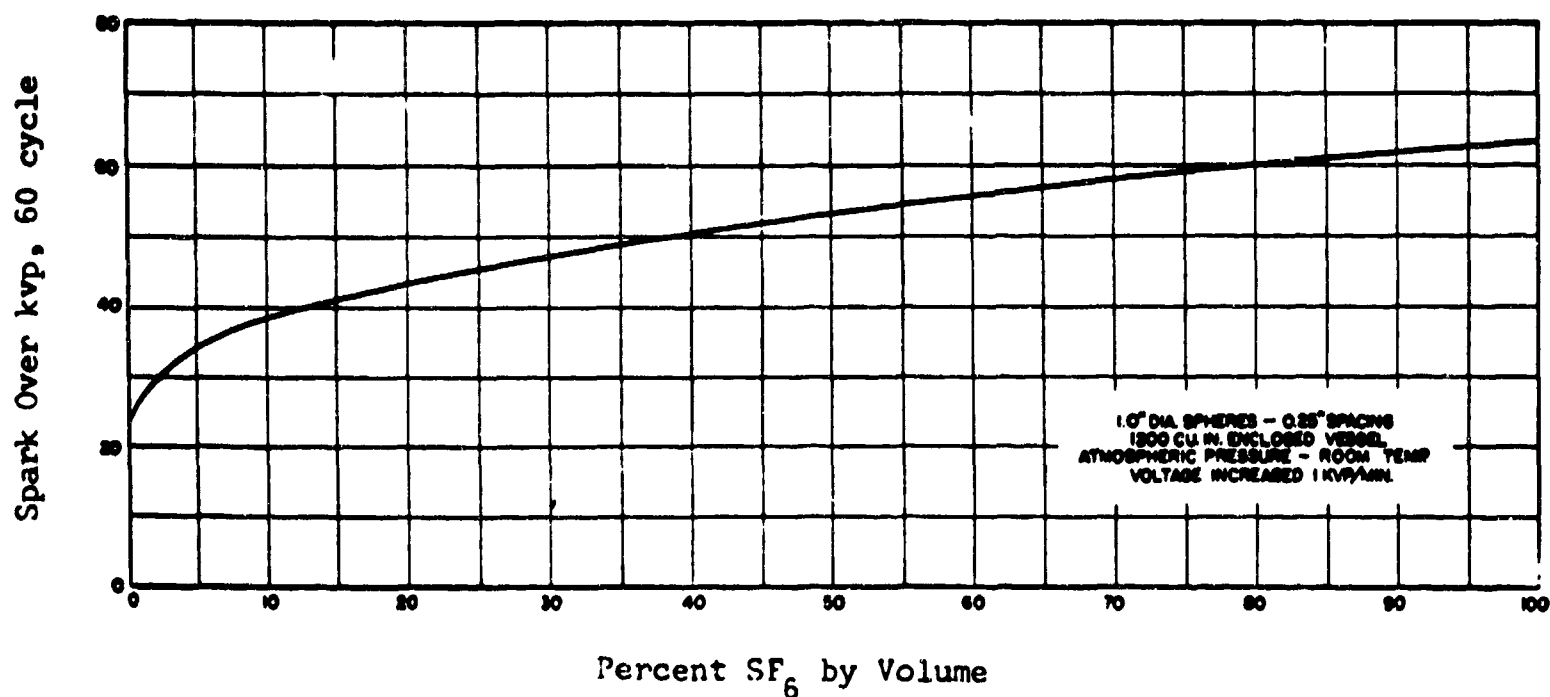
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SULFUR HEXAFLUORIDE

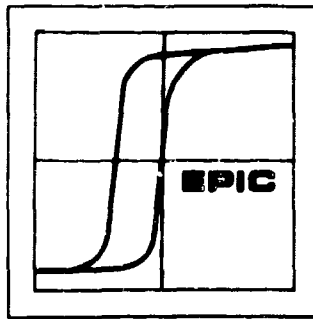
DIELECTRIC STRENGTH

(B) Dielectric Strength vs Pressure

(10) Gas Mixtures



Effect of air on dielectric strength of SF₆.



SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

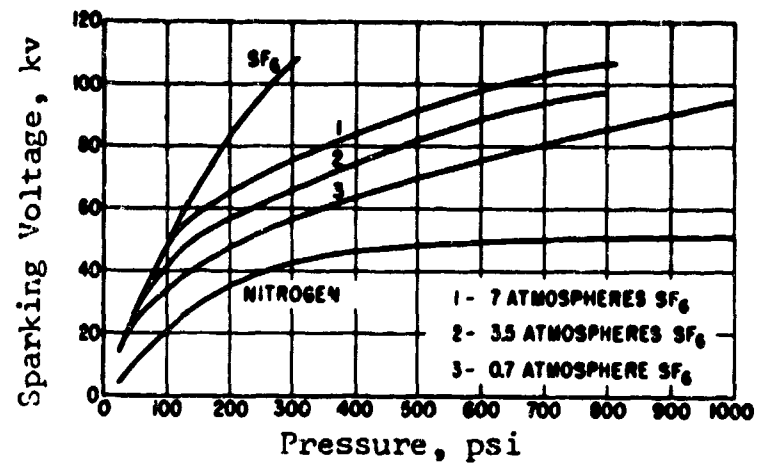
(B) Dielectric Strength vs Pressure

(10) Gas Mixtures

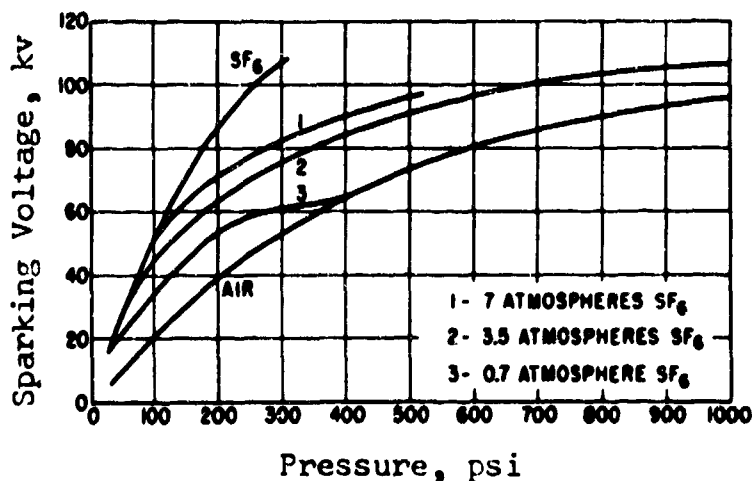
The dielectric strength of sulfur hexafluoride mixtures with nitrogen, tested in a uniform field.

Electrodes - bright mild steel
Test Gap - 1 mm

The mixtures were obtained by adding nitrogen to an initial pressure of sulfur hexafluoride as indicated.



[Ref. 16775]

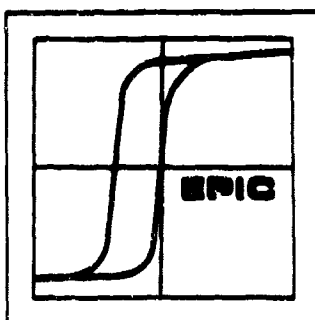


The dielectric strength of sulfur hexafluoride mixtures with air.

Electrodes - bright mild steel
Test Gap - 1 mm
Field Configuration - uniform

The mixtures were obtained by adding air to an initial pressure of sulfur hexafluoride.

[Ref. 16775]



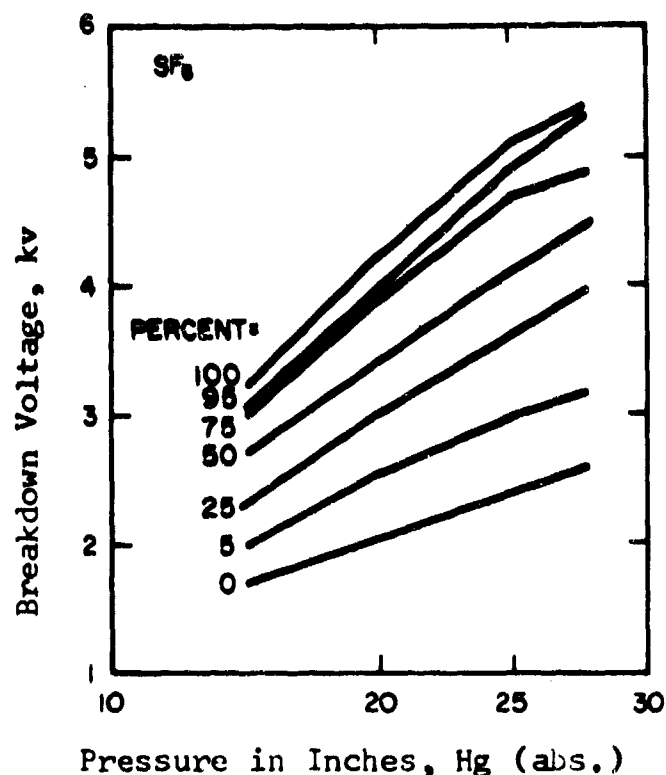
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

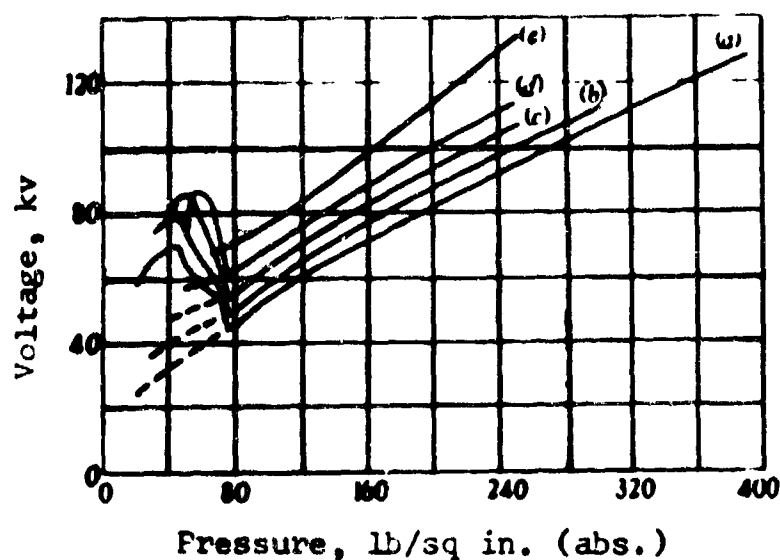
(B) Dielectric Strength vs Pressure

(10) Gas Mixtures

Breakdown voltage as a function of pressure for different percentages of sulfur hexafluoride mixed in air (across a sparkplug.)



[Ref. 10489]

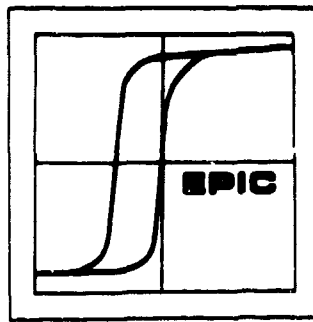


Corona onset and spark breakdown characteristics for mixtures of sulfur hexafluoride and nitrogen.

---- Corona onset voltage
— Spark breakdown voltage

- (a) 20 psi abs., $\text{SF}_6 + \text{N}_2$
- (b) 30 psi abs., $\text{SF}_6 + \text{N}_2$
- (c) 40 psi abs., $\text{SF}_6 + \text{N}_2$
- (d) 50 psi abs., $\text{SF}_6 + \text{N}_2$
- (e) 65 psi abs., $\text{SF}_6 + \text{N}_2$

[Ref. 1853]



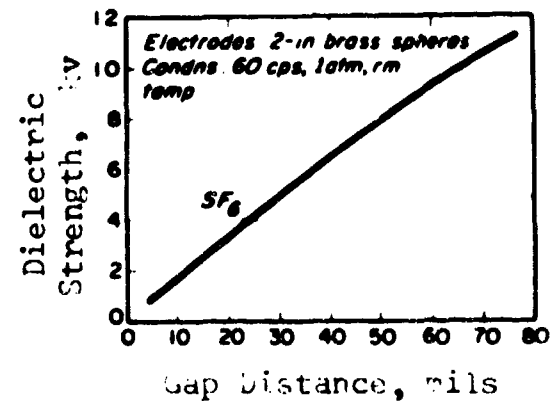
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(C) Dielectric Strength vs Gap Spacing

(1) Sphere-to-Sphere Geometry

Dielectric strength as a function of gap distance in a uniform field.

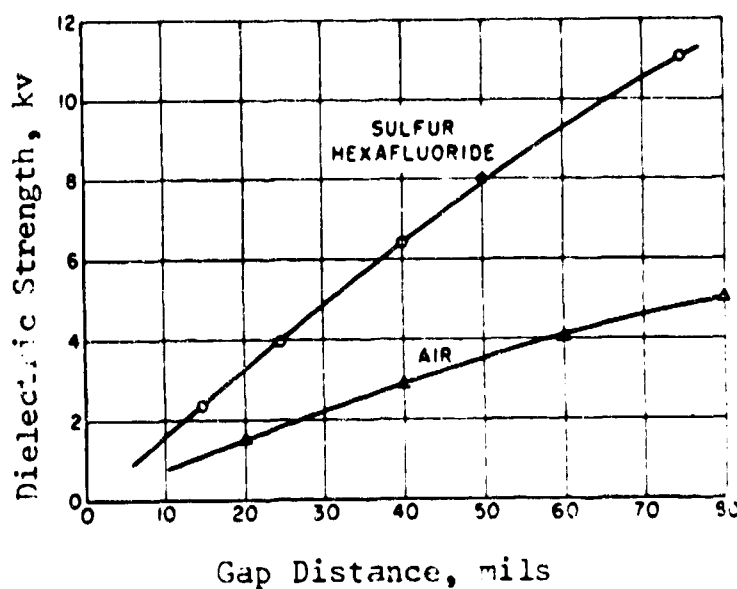


Sulfur Hexafluoride
Breakdown Voltage

[Ref. 6140]

Gap	Radio Frequency	Power Frequency
	kv peak	kv peak
0.3	26.4	27.2
0.4	34.3	36.1
0.5	44.3	45.0

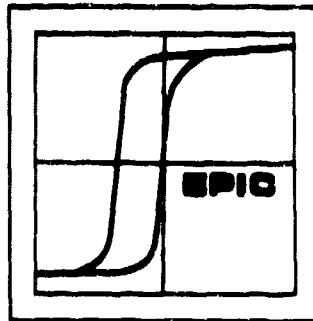
[Ref. 1181]



The dielectric strength of sulfur hexafluoride in a uniform field as affected by gap distance.

Electrodes - 2 inch brass spheres
Gas Pressure - atmospheric
Gas Temperature - room
Test Voltage - 60 cycles

[Ref. 16775]



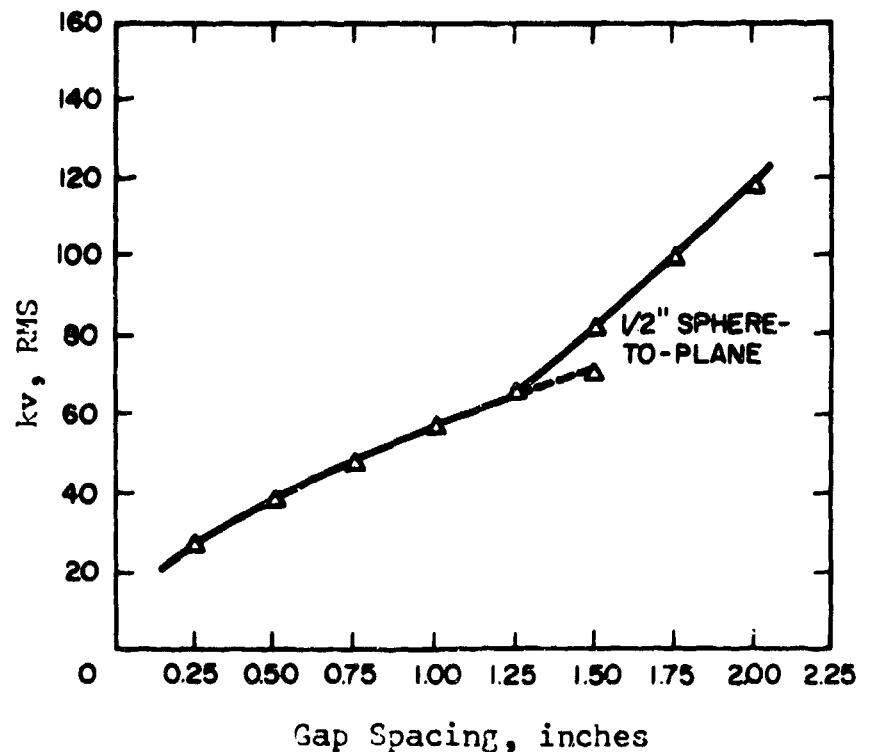
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

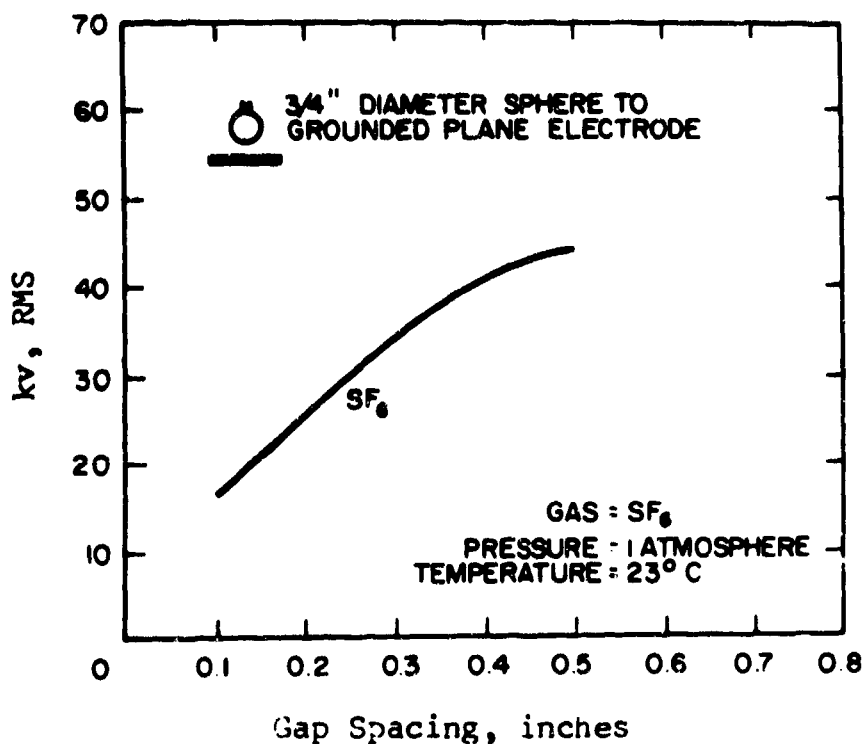
(C) Dielectric Strength vs Gap Spacing

(2) Sphere-to-Plane Geometry

60 cycle breakdown voltages of SF_6 as a function of configuration and spacing of the electrodes (at 25°C and atmospheric pressure.)

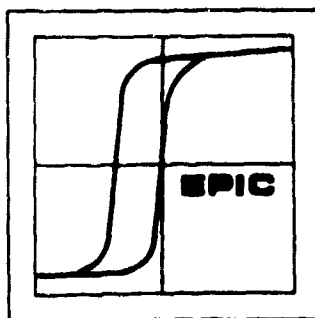


[Ref. 11279]



Rapidly applied 60 cycle voltage breakdown strength as a function of gap distance.

[Ref. 1625]



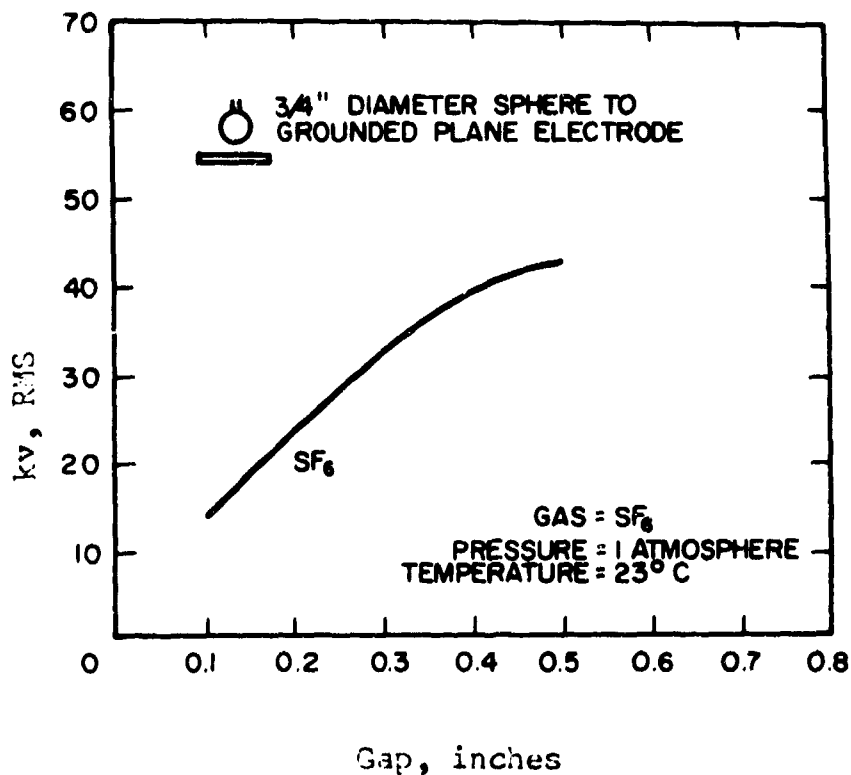
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

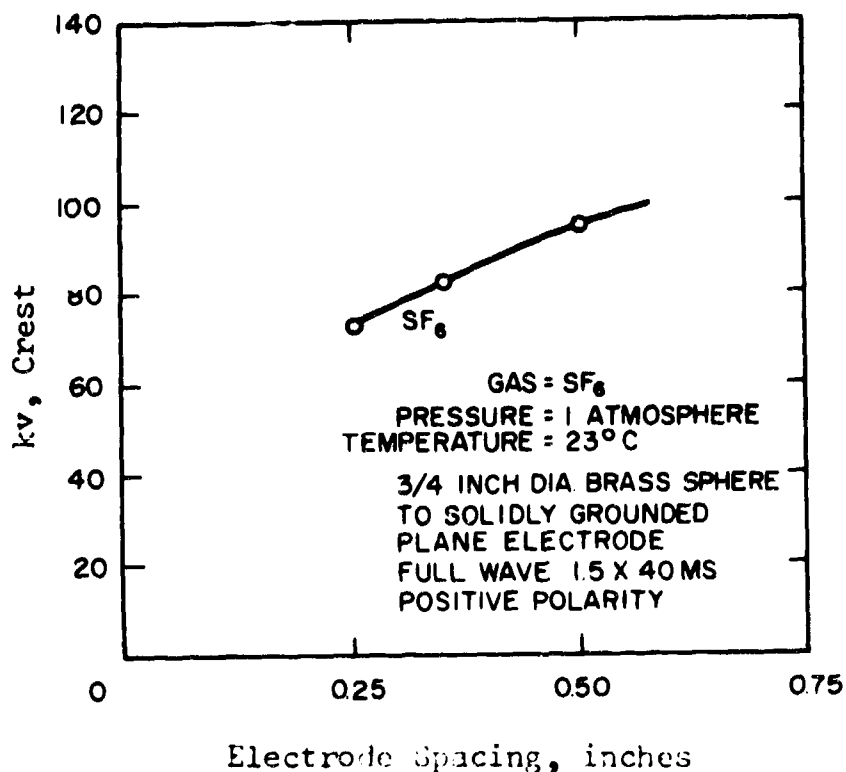
(C) Dielectric Strength vs Gap Spacing

(2) Sphere-to-Plane Geometry

One-minute withstand 60 cycle voltage strength as a function of gap distance.

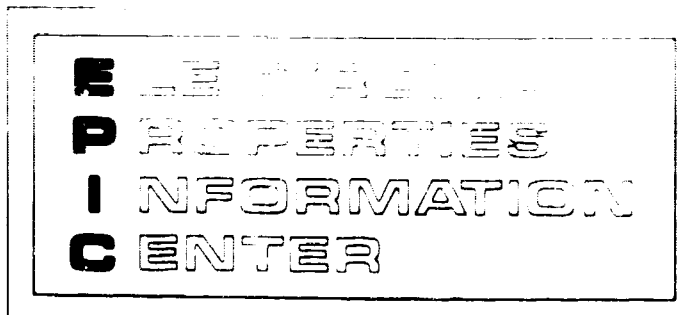
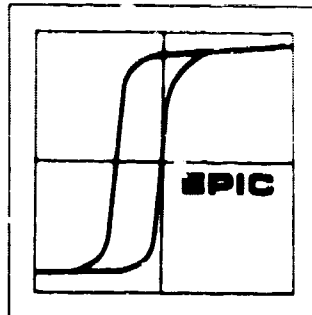


[Ref. 1625]



Impulse voltage withstand strength as a function of gap spacing.

[Ref. 1625]



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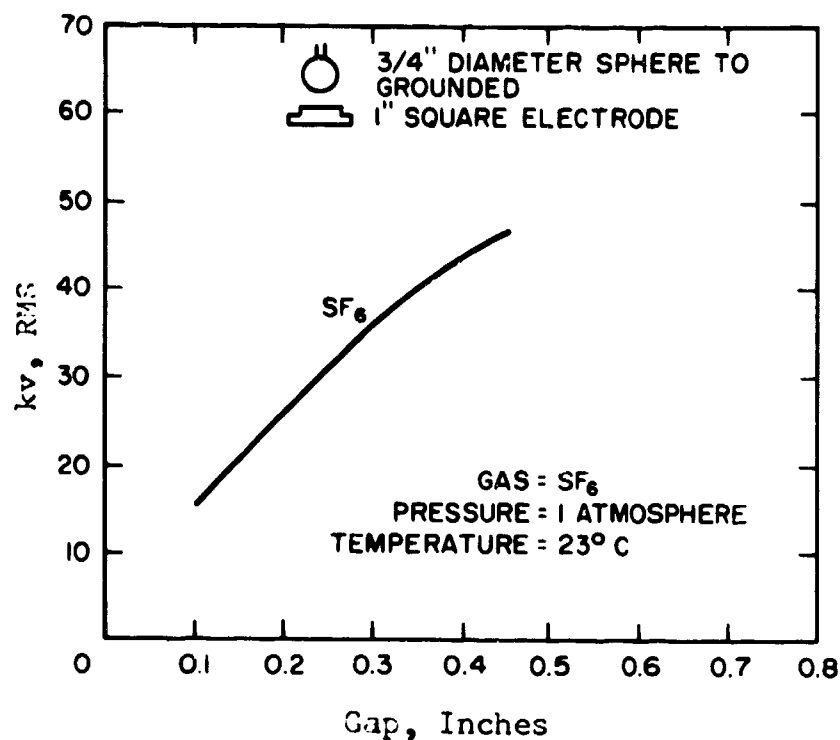
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

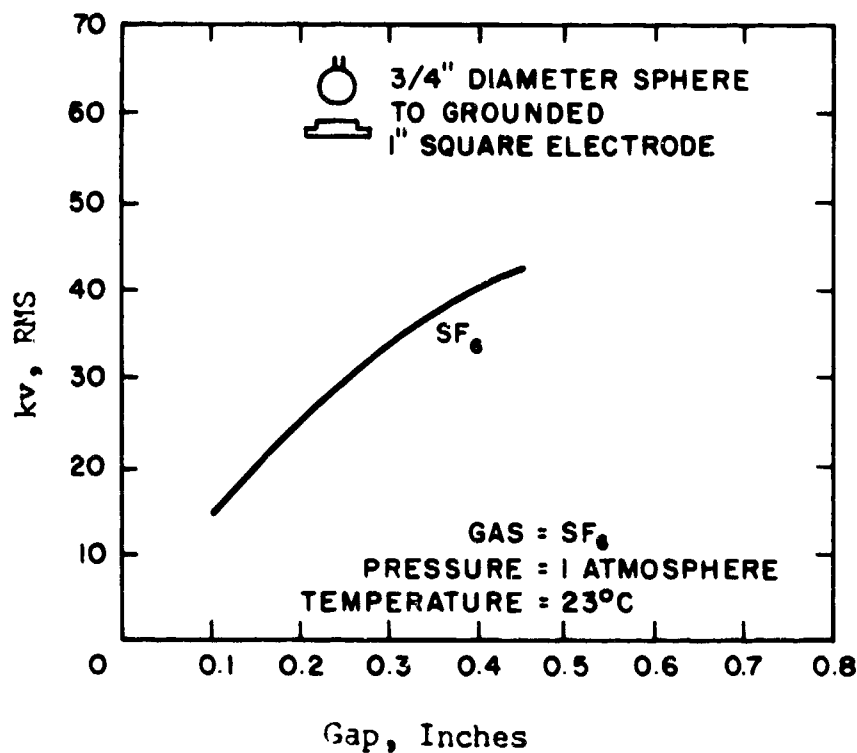
(C) Dielectric Strength vs Gap Spacing

(3) Sphere-to-Rod Geometry

Rapidly applied 60 cycle voltage
breakdown strength as a function
of gap spacing for SF_6 .

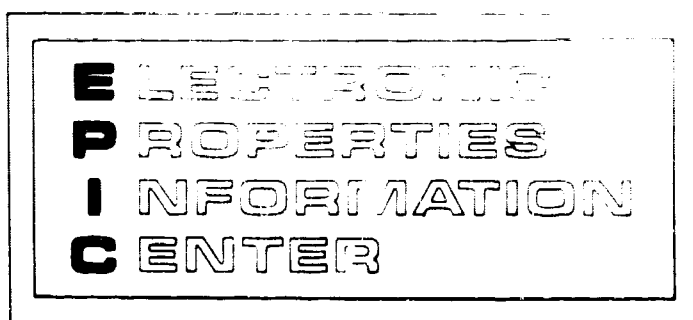
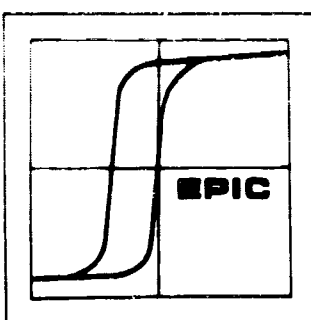


[Ref. 1625]



One-minute withstand 60 cycle
voltage strength as a function
of gap distance.

[Ref. 1625]



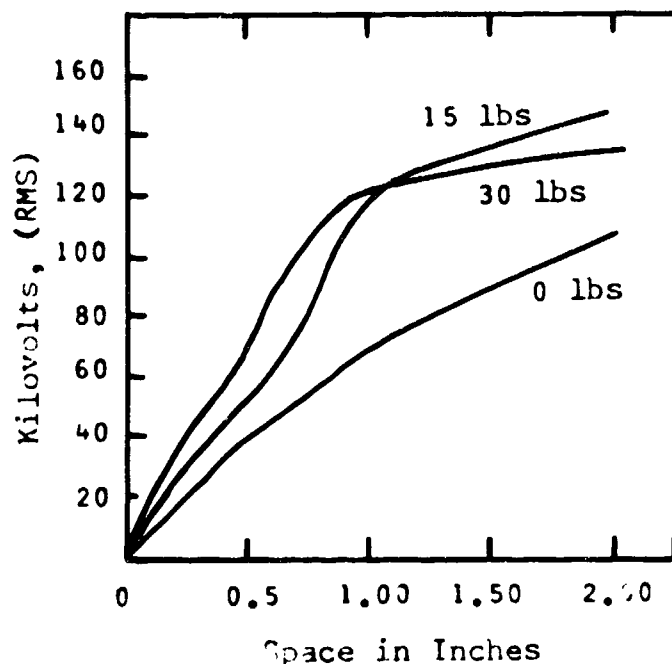
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SULFUR HEXAFLUORIDE

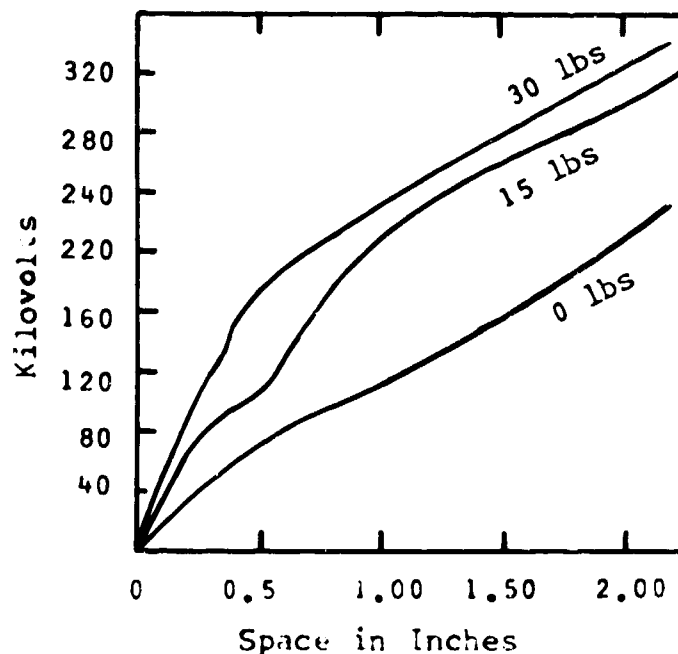
DIELECTRIC STRENGTH

(C) Dielectric Strength vs Gap Spacing

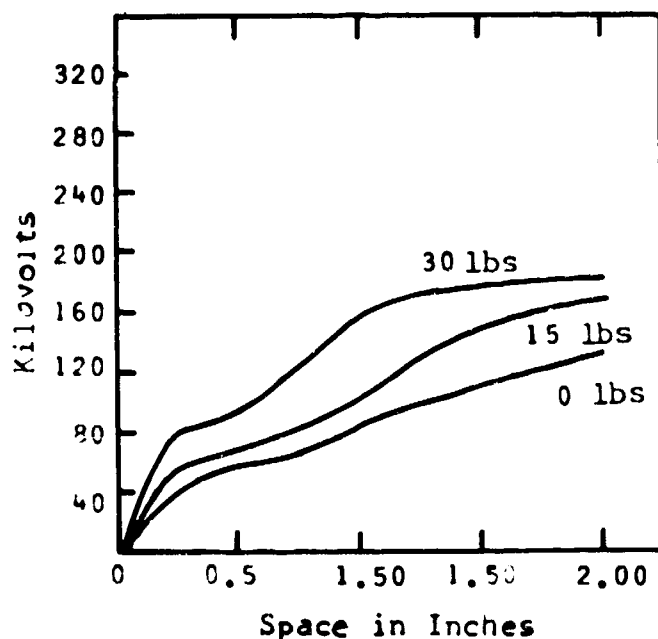
(3) Sphere-to-Rod Geometry



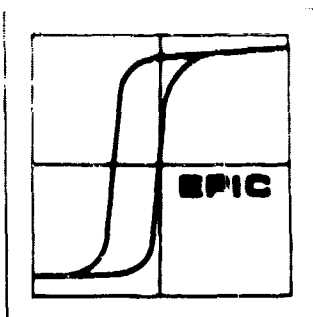
60 cycle dielectric strength of SF_6 gas. Tests made between tungsten rod and 1" diameter sphere (grounded).



Negative - impulse dielectric strength of SF_6 . Tests made between tungsten rod and 1" diameter sphere (grounded).



Positive - impulse dielectric strength of SF_6 . Tests made between tungsten rod and 1" diameter sphere (grounded).

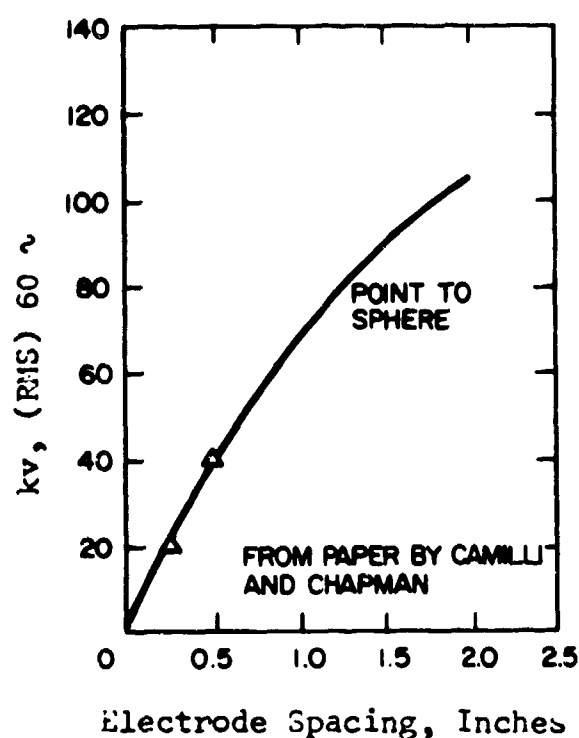


SULFUR HEXAFLUORIDE

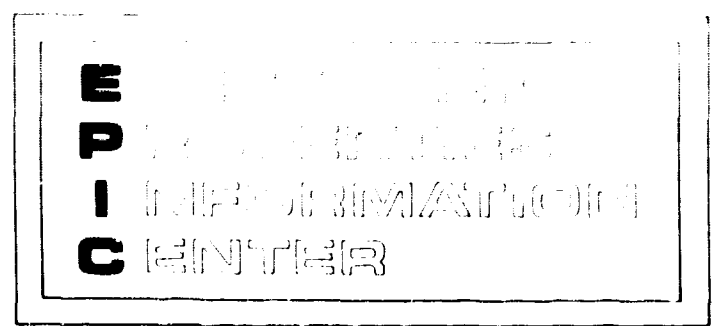
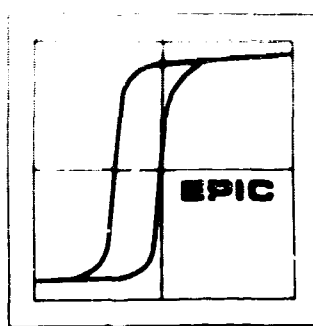
DIELECTRIC STRENGTH

(C) Dielectric Strength vs Gap Spacing

(4) Sphere-to-Point Geometry



Dielectric strength of sulfur hexafluoride as a function of electrode spacing for point to sphere configuration at atmospheric pressure and 25°C.



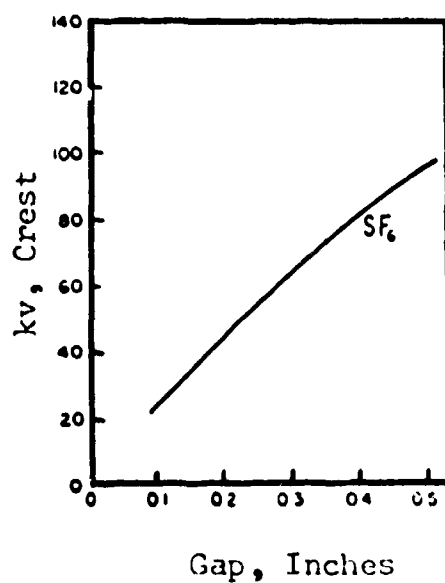
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SULFUR HEXAFLUORIDE

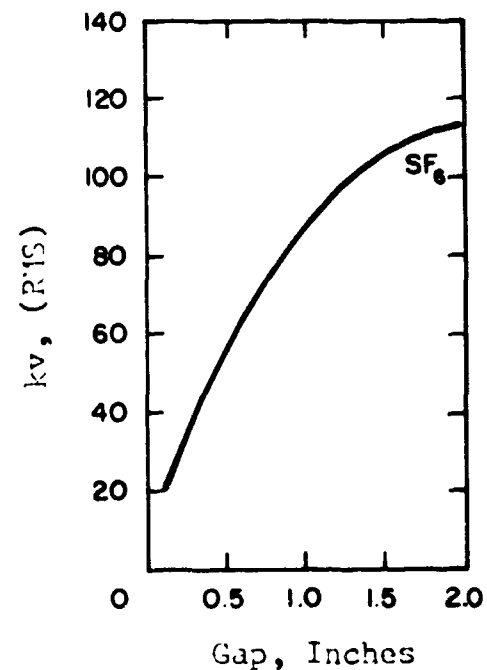
DIELECTRIC STRENGTH

(C) Dielectric Strength vs Gap Spacing

(5) Plane-to-Plane Geometry



Breakdown voltage, uniform field, 3" disks. Positive impulse 1.5 x 40 microsec.

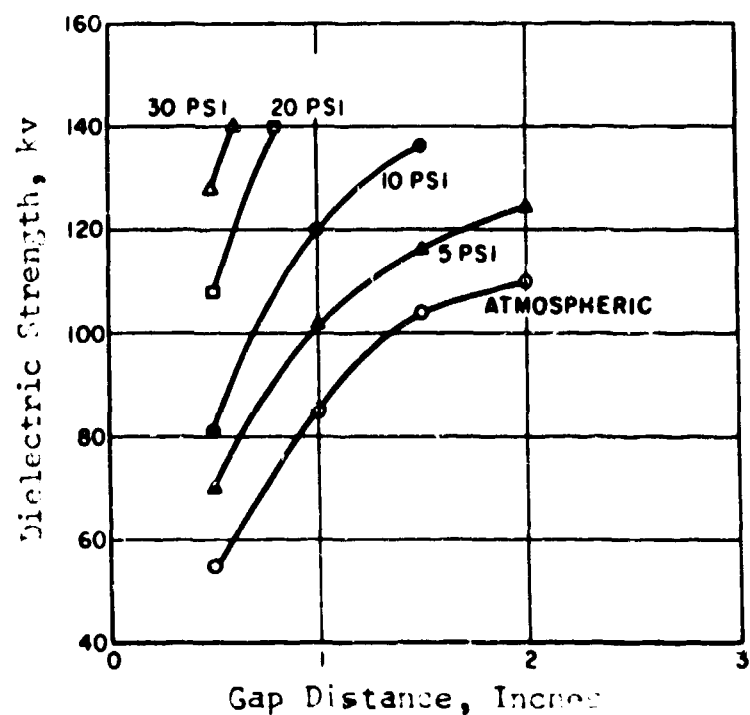


Breakdown voltage, uniform field, 3" disks.

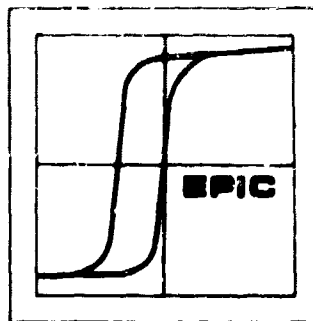
[Ref. 1860]

The dielectric strength-gap distance relation in sulfur hexafluoride gas as affected by the pressure applied.

Electrodes - 3" diameter, rounded edge planes
Temperature - room
Gas Pressure - as shown on each curve.



[Ref. 16775]



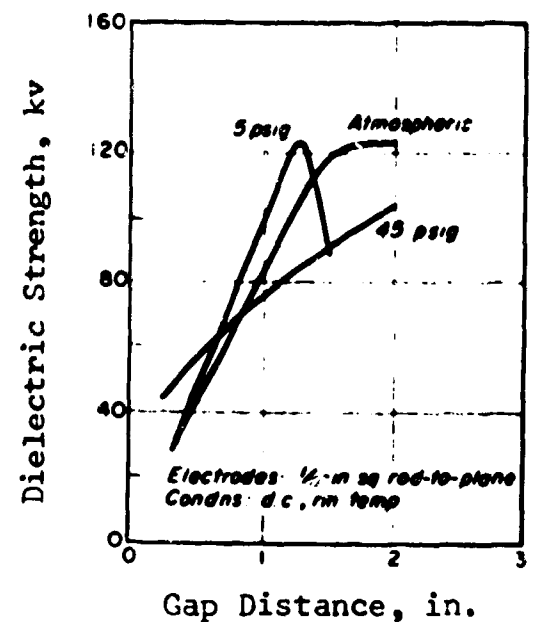
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

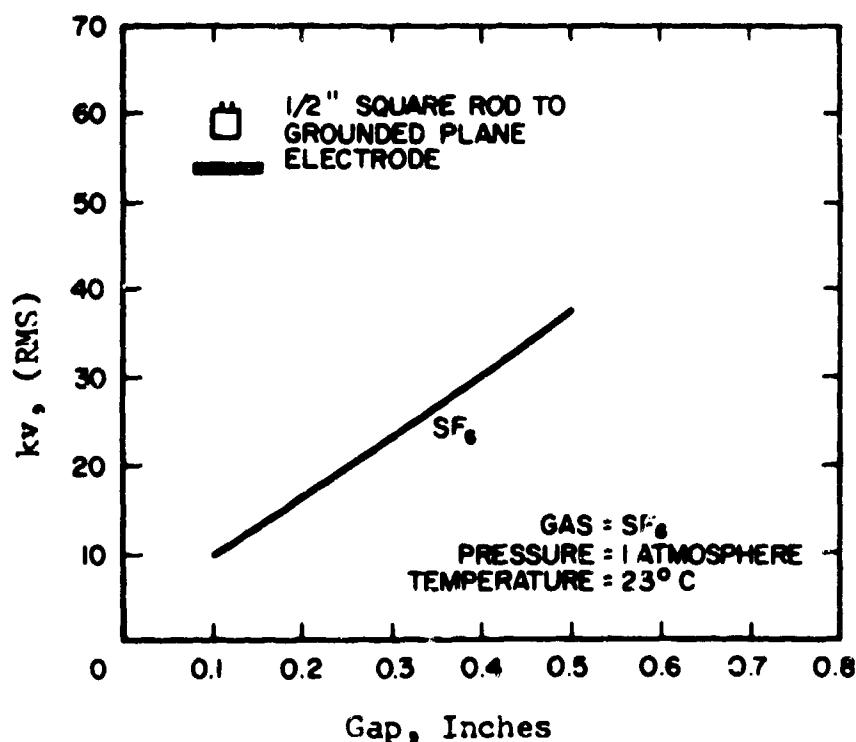
(C) Dielectric Strength vs Gap Spacing

(6) Plane-to-Rod Geometry

Gap distance-strength relationship in a non-uniform electrical field as affected by pressure. Note that dielectric strength of the gas under 5 psig pressure actually decreases as gap distance increases beyond 1 1/4 inches.

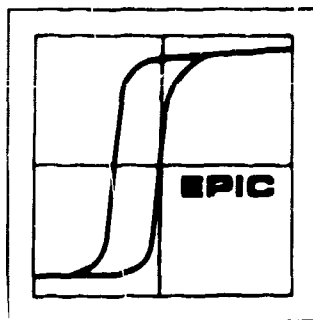


[Ref. 6140]
and
[Ref. 16775]



Rapidly applied 60 cycle voltage breakdown strength as a function of gap distance.

[Ref. 1025]



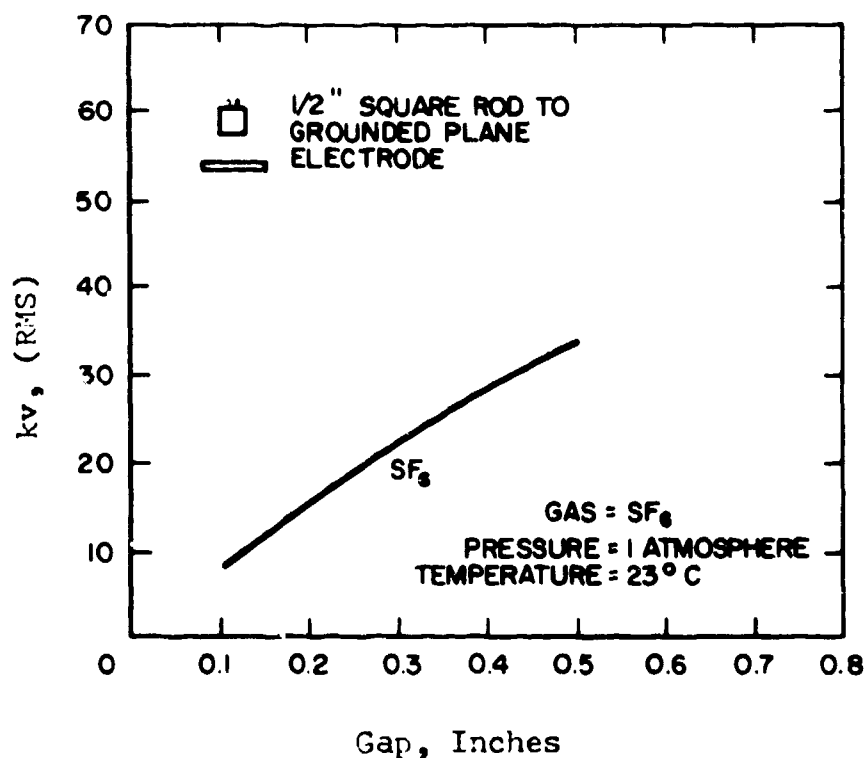
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

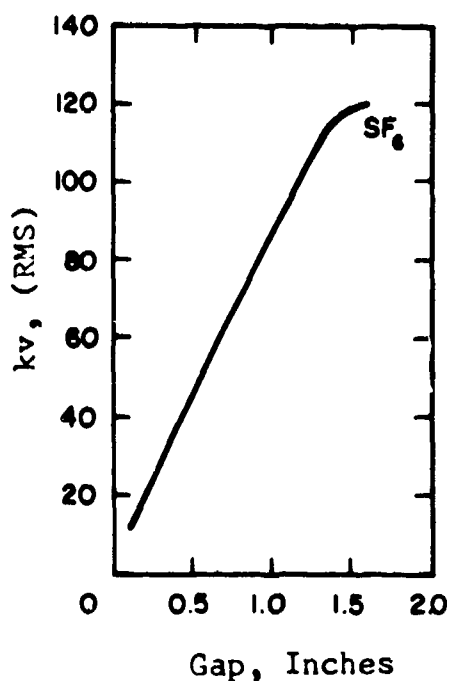
(C) Dielectric Strength vs Gap Spacing

(6) Plane-to-Rod Geometry

One-minute withstand 60 cycle voltage strength as a function of gap distance.

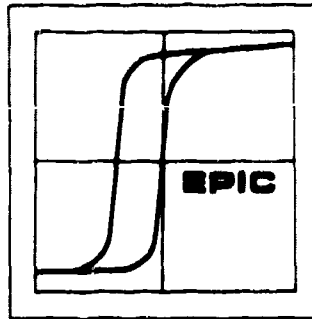


[Ref. 1625]



Breakdown voltage, nonuniform field,
1/4" rod.

[Ref. 1860]



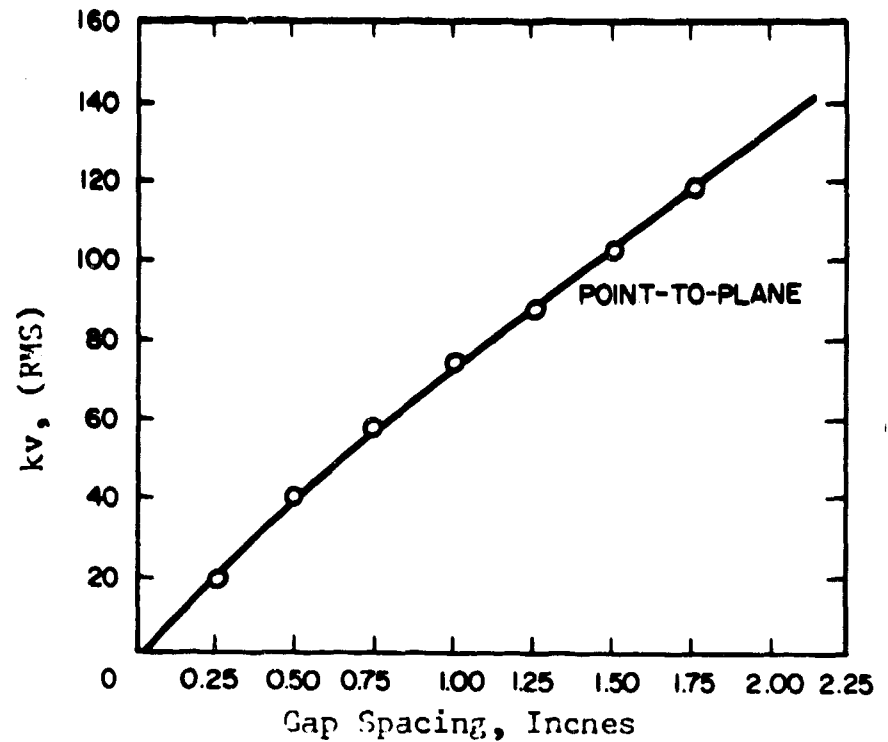
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

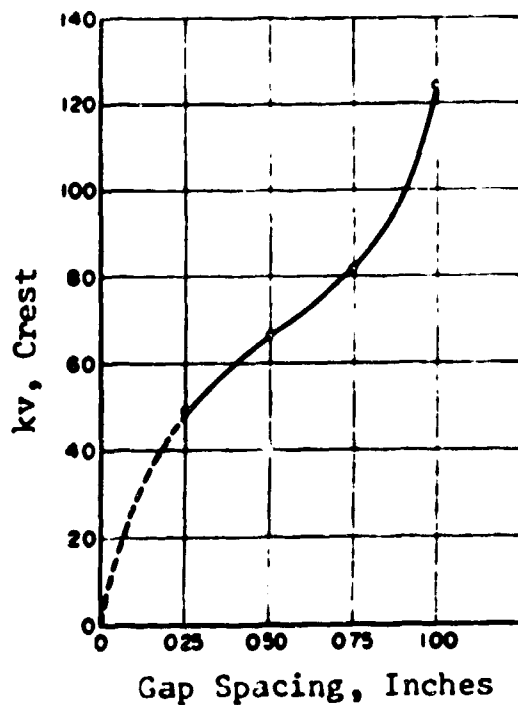
(C) Dielectric Strength vs Gap Spacing

(7) Plane-to-Point Geometry

60 cycle breakdown voltages of SF_6 for point-to-plane configuration as a function of gap spacing.

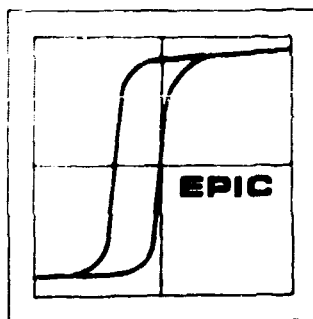


[Ref. 11279]



a.c. sparkover voltage of SF_6 as a function of electrode spacing between a 1/16 inch hemisphere point and a 6 inch diameter plane at 3 atmospheres pressure.

[Ref. 11302]



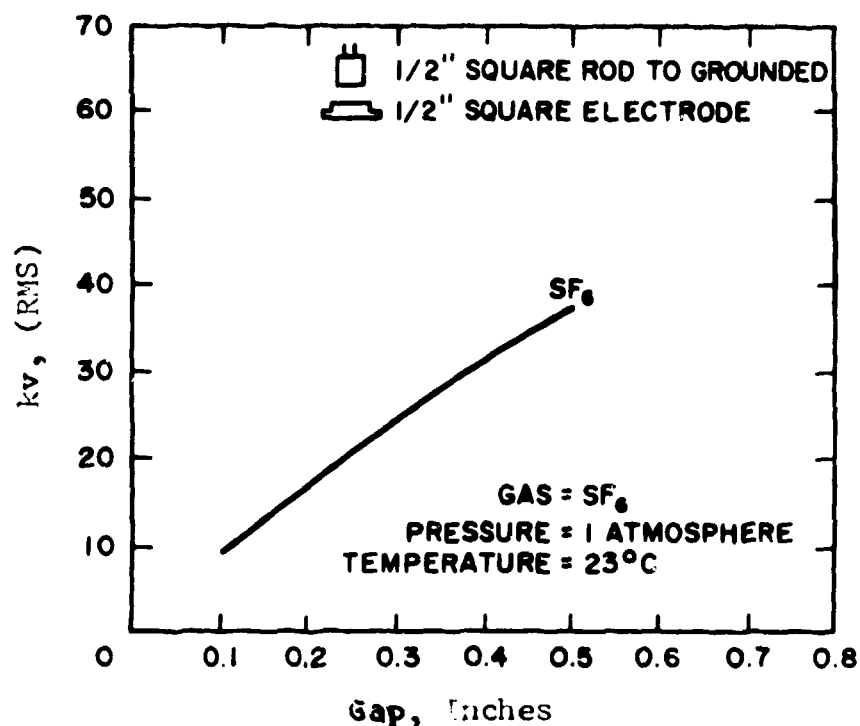
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

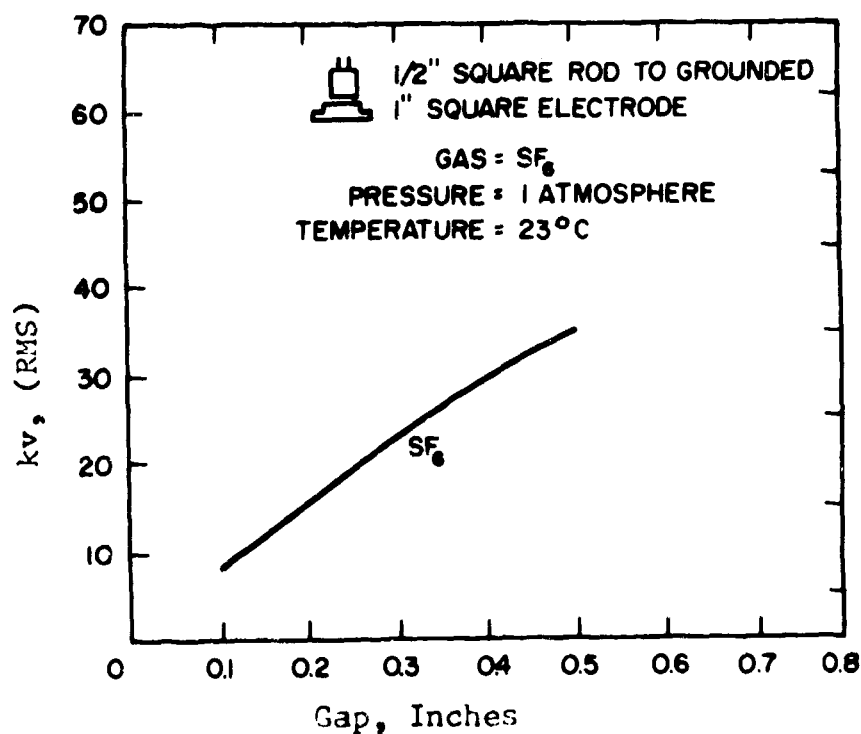
(C) Dielectric Strength vs Gap Spacing

(8) Rod-to-Rod Geometry

Rapidly applied 60 cycle voltage
breakdown strength as a function
of gap spacing.

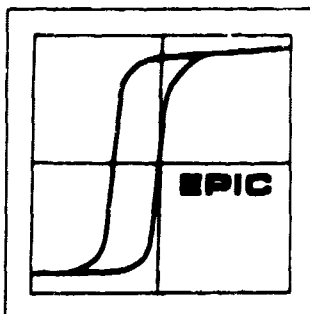


[Ref. 1625]



One minute withstand 60 cycle
strength as a function of gap
spacing.

[Ref. 1625]

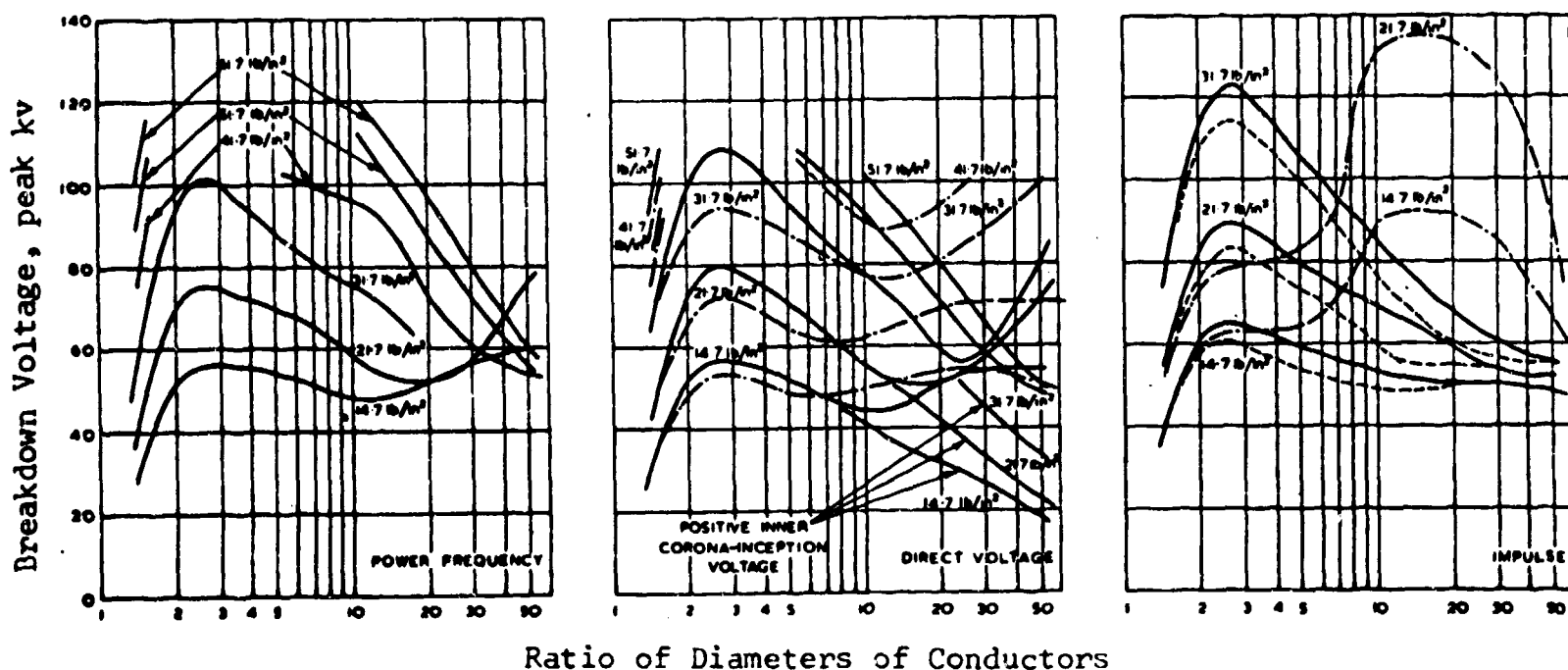


SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

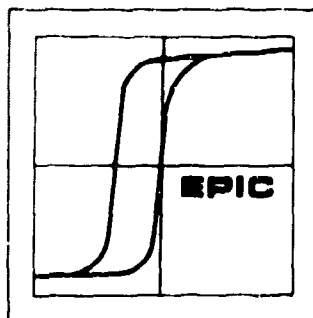
(C) Dielectric Strength vs Gap Spacing

(9) Coaxial Cylinder Geometry



Breakdown voltage for sulfur hexafluoride between coaxial cylinders.

- Power frequency, positive d.c. and impulse
- Negative d.c. and impulse
- Positive impulse with radium



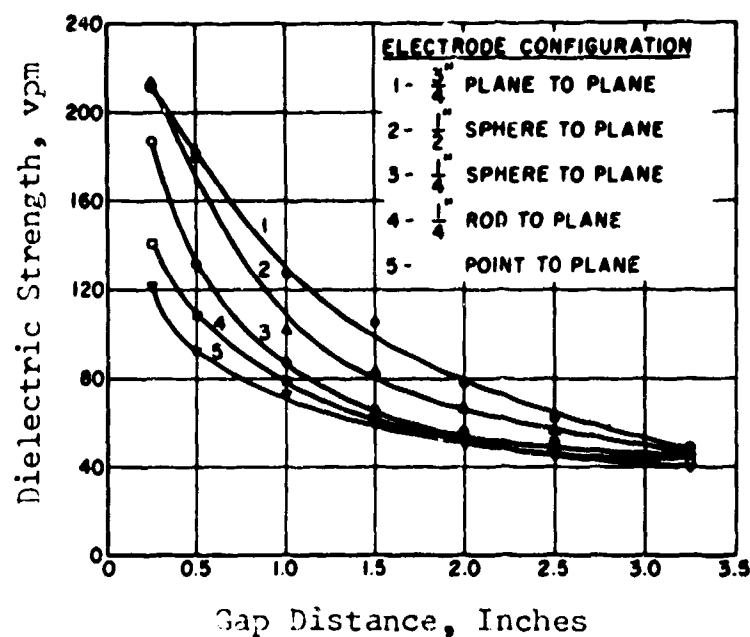
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

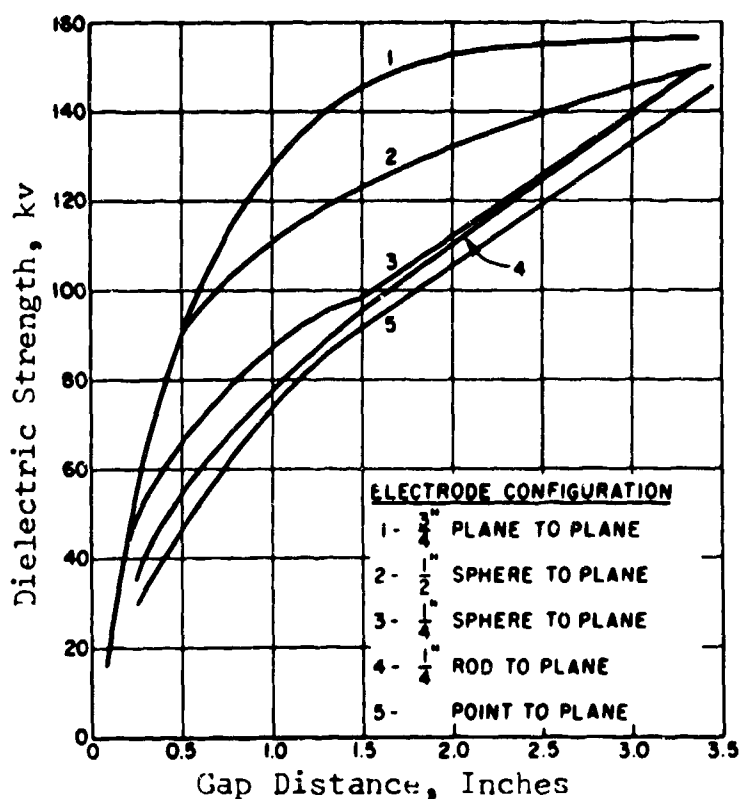
(C) Dielectric Strength vs Gap Spacing

(10) Various Configurations

The effect of electrode configuration on the dielectric strength of sulfur hexafluoride as a function of gap distance at atmospheric pressure when tested under impulse conditions.



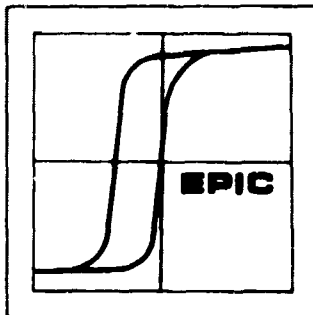
[Ref. 16775]



The dielectric strength-gap distance relation for sulfur hexafluoride gas as a function of the electrode configuration measured at atmospheric pressure.

Test temperature - 25°C
Voltage Wave Form - 1 1/2 x 40
microseconds
Polarity - positive

[Ref. 16775]



SULFUR HEXAFLUORIDE

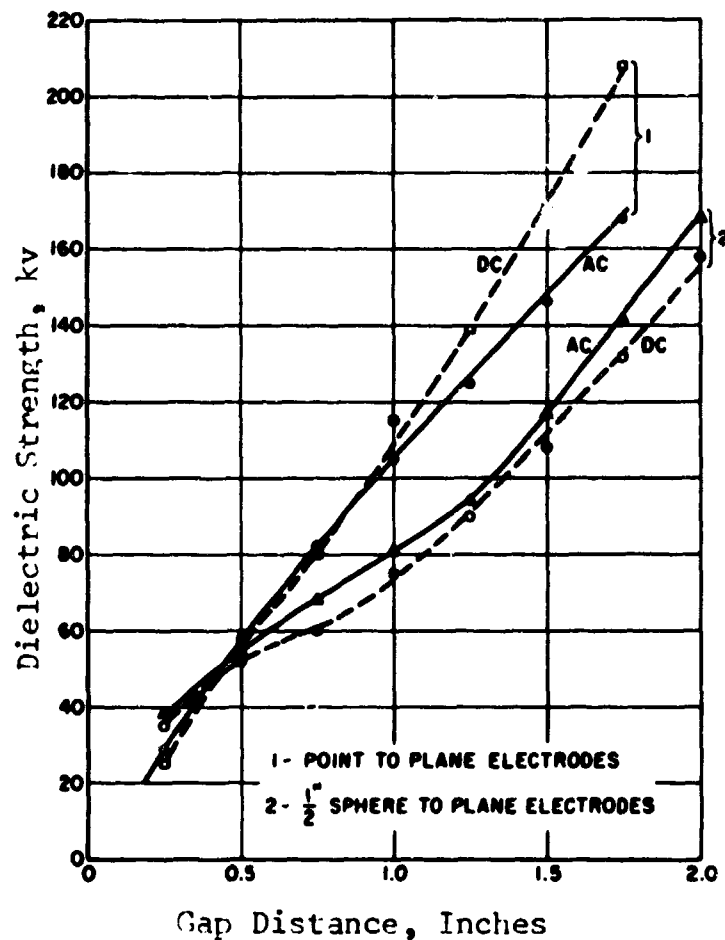
DIELECTRIC STRENGTH

(C) Dielectric Strength vs Gap Spacing

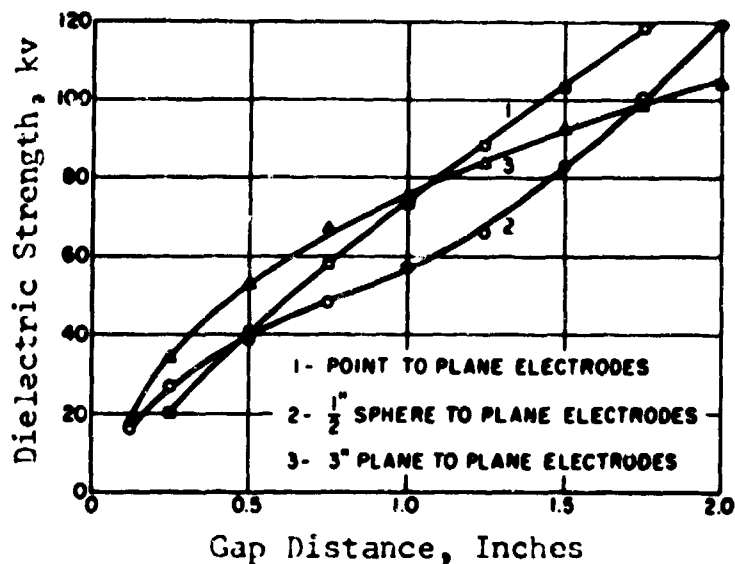
(10) Various Configurations

The comparative dielectric strength of sulfur hexafluoride gas tested under dc and ac voltage at room temperature and pressure.

ac voltage - 60 cycles
dc polarity - positive



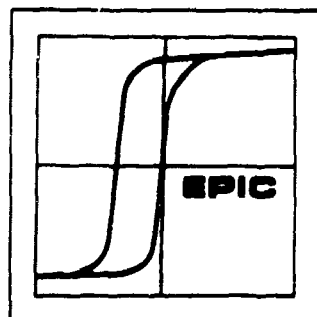
[Ref. 16775]



The effect of electrode configuration on the dielectric strength of sulfur hexafluoride gas at atmospheric pressure.

Test temperature - room
Test voltage - 60 cycles

[Ref. 16775]

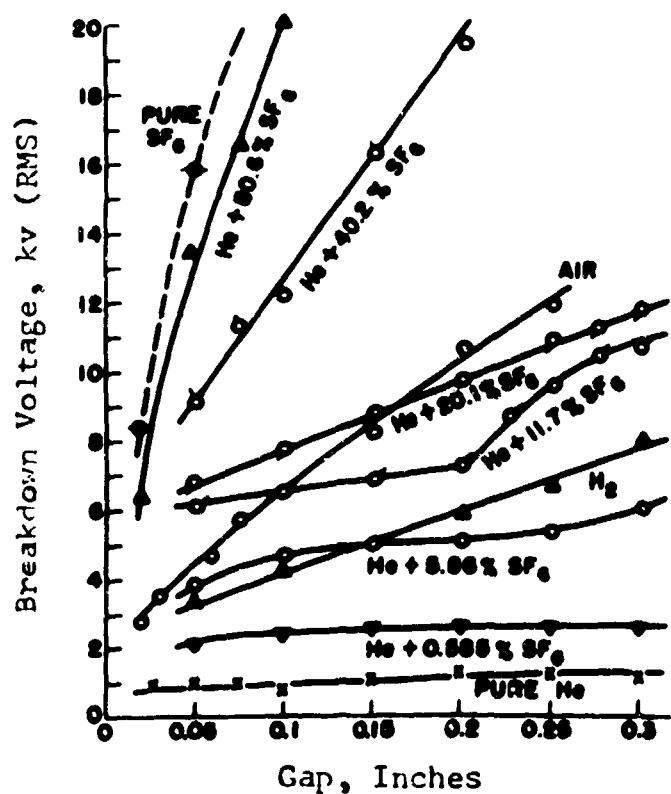


SULFUR HEXAFLUORIDE

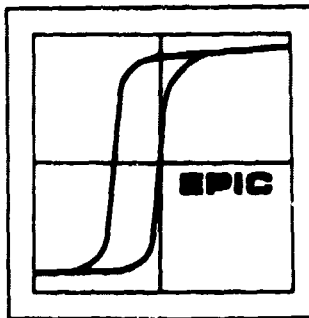
DIELECTRIC STRENGTH

(C) Dielectric Strength vs Gap Spacing

(11) Gas Mixtures



Spark breakdown voltages for air, He, H₂, SF₆ and mixtures of He + SF₆ for 1 inch diameter hemispheres. (74.6 centimeters Hg, 29.5 degrees centigrade, 60 cycle voltage.)

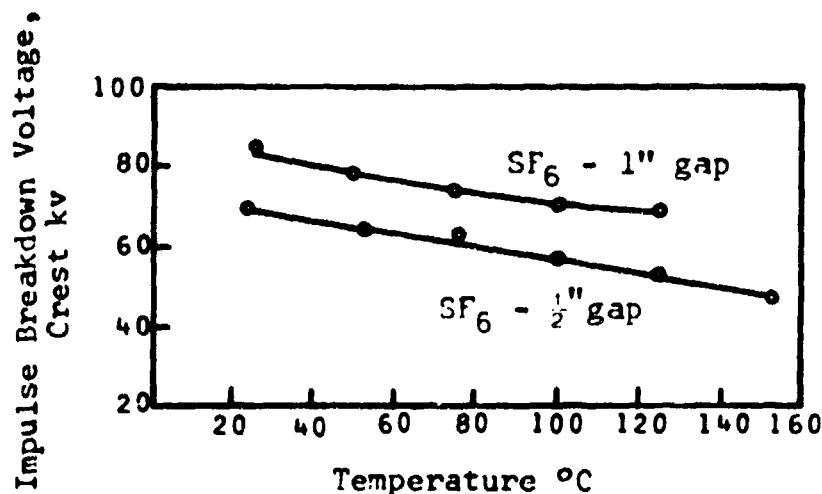


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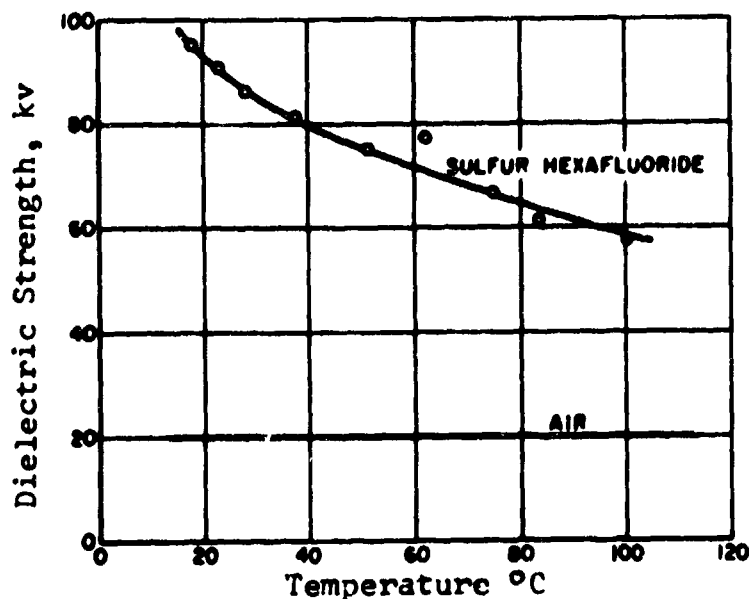
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

(D) Dielectric Strength vs Temperature



Impulse breakdown voltages of sulfur hexafluoride at atmospheric pressure as a function of temperature.



[Ref. 11279]

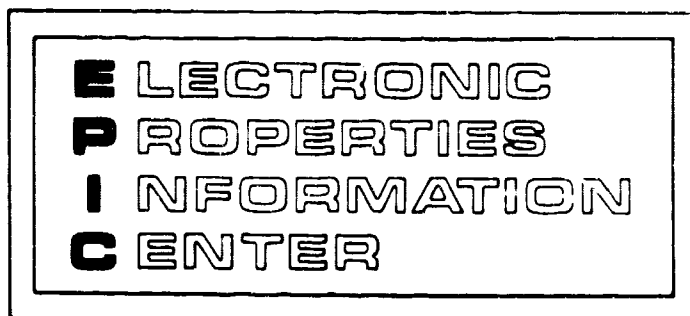
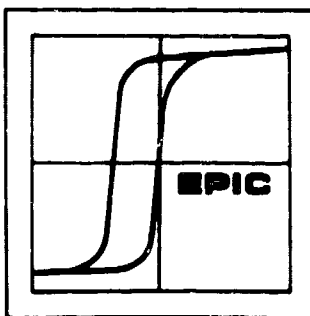
The dielectric strength-temperature relation for sulfur hexafluoride tested at atmospheric pressure.

Electrodes - 1/2 inch sphere-to-plane

Gap Distance - 1/2 inch

Voltage - 1 1/2 x 40 microsecond wave form

[Ref. 16775]



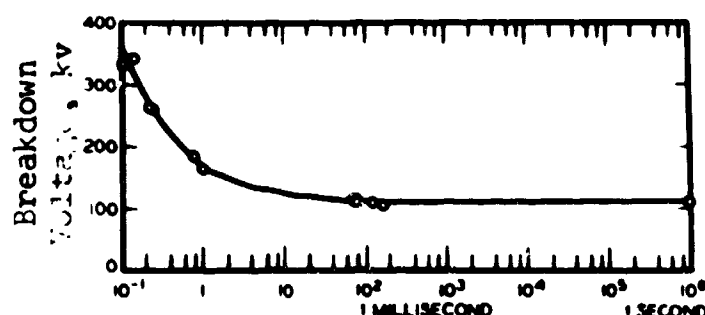
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SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

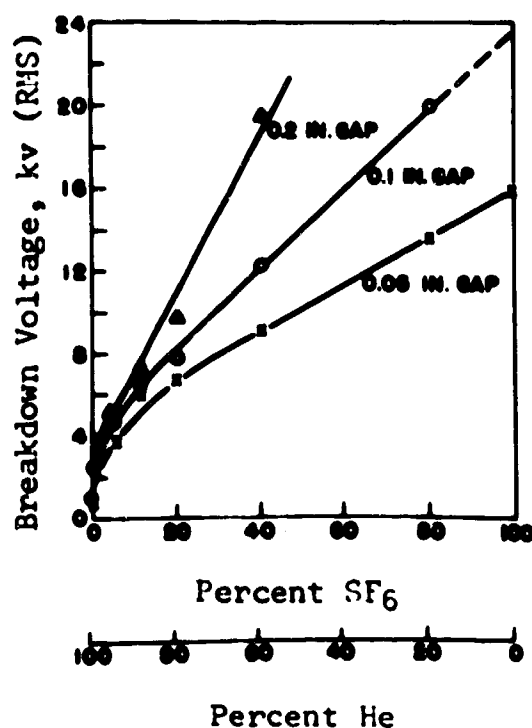
(E) Miscellaneous Breakdown Parameters

Breakdown voltage as a function of time to breakdown for SF_6 for 2 inch gap between 2 inch diameter sharp-edged electrode and 6 inch diameter plane in 12 inch steel tank at 78.5 cm mercury absolute and 25°C for positive polarity.



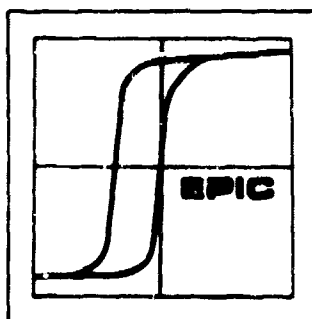
Time of Rise of Voltage to Breakdown Voltage, μsec

[Ref. 6209]



Spark breakdown voltage for $\text{SF}_6 + \text{He}$ mixtures. Parameter + gap between 1 inch diameter hemispheres (74.6 cm Hg, 29.5°C).

[Ref. 1931]



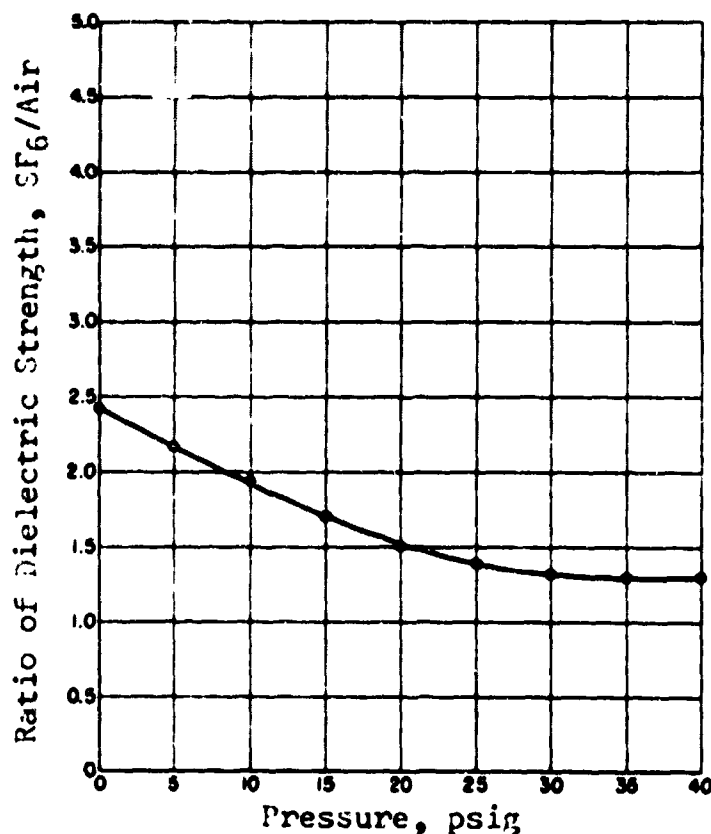
SULFUR HEXAFLUORIDE

DIELECTRIC STRENGTH

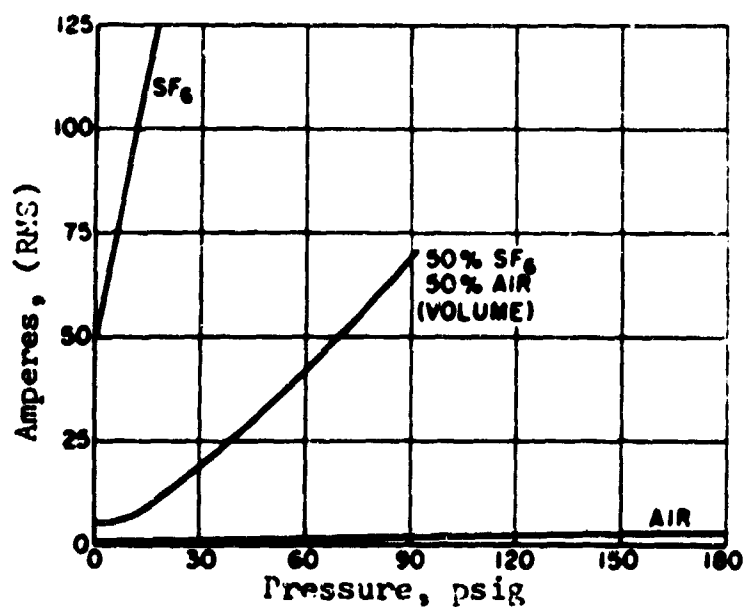
(E) Miscellaneous Breakdown Parameters

Showing the changing relation of the impulse voltage breakdown of sulfur hexafluoride and air as the gas pressure of each is increased.

electrodes - point-to-plane
test gap - 1 1/2 inches
voltage wave form - 1 1/2 x 40 μ sec
point electrode polarity - positive
test temperature - 27°C

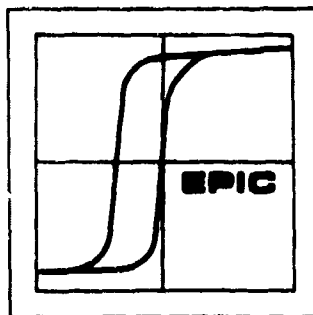


[Ref. 16775]



Showing the interrupting capacity of sulfur hexafluoride gas, air and a 50% mixture thereof at 2300 volts, zero power factor, using a three inch plain break switch.

[Ref. 16775]



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SULFUR HEXAFLUORIDE

DISSIPATION FACTOR

		Ref.
at 1 atm. pressure	$\tan \delta = < 2 \times 10^{-7}$	11266
at 21 atm. pressure	$\tan \delta = < 5 \times 10^{-6}$	11266
at $-50 \pm 1^\circ\text{C}$ (10-500Kc) (liquid SF_6)	$\tan \delta = < 0.001$	1508

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